POGIL™

Activities for High School Chemistry

Developed through the High School POGIL Initiative
Laura Trout, Editor-in-Chief

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Preface

This activity collection is the product of a three-year effort (2008–2011) to bring student-centered, guided-inquiry instruction to secondary level classrooms, based on the principles of Process Oriented Guided-Inquiry Learning (POGIL), a group-learning, research-based instructional strategy.

In a POGIL classroom, students work cooperatively in self-managed teams, using carefully designed materials, such as the activities included in this collection, that guide them to construct new understandings while they simultaneously develop key process skills, including critical thinking, problem solving, and collaboration.

The POGIL Project (www.pogil.org) is an independent not-for-profit organization, housed at Franklin & Marshall College, whose mission is to connect and support educators from all disciplines interested in implementing, improving, and studying student-centered pedagogies and learning environments. The POGIL Project has received more than $6 million in National Science Foundation (NSF) funding, $600,000 from the U.S. Department of Education, and $564,000 from private foundations.

Since its inception in 2003, The POGIL Project has grown beyond its initial target audience of science faculty at higher education institutions to include more than 1,500 practitioners in its network of implementers at colleges, universities, and high schools in every state in the country. The POGIL Project has presented more than 250 workshops and events, which have been attended by more than 6,500 people.

These HSPI activities contain several features which make them easy to use. Each activity has a "Teacher Resources" section, where you will find clear learning objectives, prerequisites, assessment questions, and teacher tips about facilitating the lesson. Within the activity, you will find stop signs at strategic points. These indicate good places for reporting out as a whole class or using other methods to check for understanding before moving on. Key icons mark questions containing important content which directly relate to the learning objectives. Each of these HSPI activities also includes optional extension questions. These questions go beyond the learning objectives stated in the teacher resources, and therefore truly are optional. They help to differentiate the learning experience in your classroom, and keep faster moving groups occupied while others finish the required questions.

Understanding effective classroom implementation is essential for a successful experience when using POGIL materials with students. We encourage everyone who plans to incorporate these activities into their classes to learn more about effective classroom strategies for student-centered work. The POGIL Project offers a wide array of training opportunities, including: webinars, presentations at regional and national conferences (ACS, NABT, BCCE, ChemEd, NSTA), introductory workshops, multiday regional workshops each summer, and custom workshops as requested.

Also available through The POGIL Project Web site is our interactive *Implementation Guide*. This web-based guide includes resources and materials to help you and your students get the maximum instructional benefits from incorporating these activities into your classroom.

Visit www.pogil.org for more information about The POGIL Project, to access the *Implementation Guide,* to see our events schedule and registration information or to request a workshop to be held at your institution.

Acknowledgments

The High School POGIL Initiative (HSPI) was supported by a generous grant from the Toyota USA Foundation. This funding enabled The POGIL Project to bring together high school teachers from across the country to serve as authors, reviewers, editors and classroom testers of these activities. We thank the members of the HSPI leadership, the editors, content advisors and our writing partners for their contributions throughout the course of the project. Their tireless efforts made this endeavor a success.

Special thanks go to Laura Trout, Editor-in-Chief, and Cindy Wingenroth, HSPI Coordinator.

To Laura for her vision, her belief that high school students could benefit from this type of learning environment, and her leadership that helped guide and shape this project.

To Cindy for her enthusiastic and unflagging efforts to keep this project—and all the people involved—moving forward.

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Safety First

What practices are followed to ensure safety in the laboratory?

Why?

Academic laboratory accidents are estimated to occur 10–50 times more frequently than chemical plant accidents. Laboratory accidents often have unexpected outcomes that may result in permanent injury. Dressing appropriately and following laboratory safety rules will reduce the incidence and severity of accidents and help keep students safe.

1. Create a laboratory safety diagram in the space below by doing the following:
   a. Sketch the outline of your laboratory room including all doors and windows

   b. Mark and label the position of the following laboratory safety equipment.
      1. Fire blanket
      2. Fire extinguisher
      3. Safety shower
      4. Eyewash station
      5. Fume hood
      6. Chemical disposal area
      7. Broken glassware disposal
      8. Chemical spill clean-up kit
      9. Location of goggles
      10. Location of gloves

   c. Locate and read the evacuation instructions that are posted in your laboratory. Describe how you should evacuate in case of an accident.

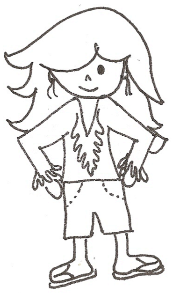
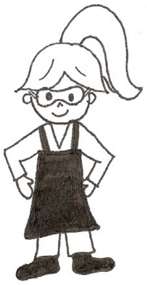
   d. Label the fire exits in the diagram and add the evacuation route to your picture (this should be posted in your room).

Laboratory Safety Diagram

2. Biohazard materials are disposed of in biohazard bags when you are finished working with them.
   a. On the diagram above, label where the bags are generally located.

   b. What color are the bags?

Model 1 – Laboratory Attire

This student is dressed **inappropriately** for laboratory work.	This student is dressed **appropriately** for laboratory work.
	

3. Look at the two students in the model above.
   a. List at least three inappropriate items of dress for the student on the left.

   b. List at least three appropriate items of dress for the student on the right.

4. Why wear goggles while working with chemicals and glassware?

5. When working with a Bunsen burner what precautions should be taken with respect to your clothing and hair?

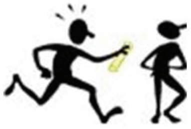
6. Why should one avoid wearing shorts or skirts while working with chemicals and with glassware?

7. What type of shoes should a student wear while working with chemicals and with glassware?

8. If an accident occurred in the laboratory, which of the two students in the model would have protection provided by their clothing? Why?

Model 2 – Scenes in the Lab

1



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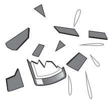

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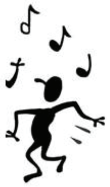

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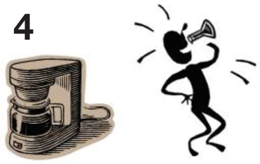

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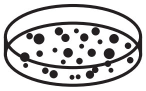

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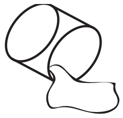

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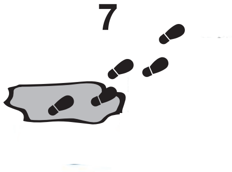

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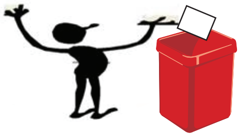

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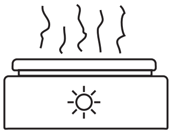

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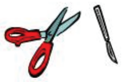

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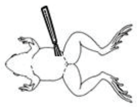

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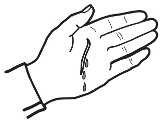


9. Complete the table below using the pictures in Model 2.

Scene	Potential Concern	Proper Safe Behavior
1		
2	Broken or chipped glassware	
3		
4		
5	Bacteria growing in an open Petri dish—could spread to other areas.	
6		
7		
8	Dispose of waste in designated locations.	
9	Hot plate turned on, could cause burns.	
10		Dispose of used scalpel blades in a sharps container; put all scissors away when finished.
11		
12		

Read This!

Communication with your teacher in the laboratory can also help prevent accidents or injuries to yourself and others. For example, you should always tell your teacher if you spill something or are cut or injured when performing an experiment. You should also alert your teacher if any equipment or glassware is broken. Your teacher can provide Material Safety Data Sheets (MSDS), which contain safety information about chemicals you may come in contact with in the laboratory. Chemicals should be disposed of safely, as directed by your teacher. Do not dump chemicals into the sink or trash.

---

10. Suppose you spill a chemical on yourself:
    a. What information can your teacher provide for you concerning that chemical?

    b. Where is the information located?

11. Why is it important to let your teacher know if you cut, burn or injure yourself when performing an experiment?

12. Why should you tell your teacher if any equipment or glassware is broken?

13. Why should you never perform unauthorized experiments or ignore written directions for an experiment?

14. Your teacher asks your group to create a list of ten rules that everyone must follow in the laboratory. What rules would your group include? After developing a list, send a representative from your table to another group to compare responses.

STOP

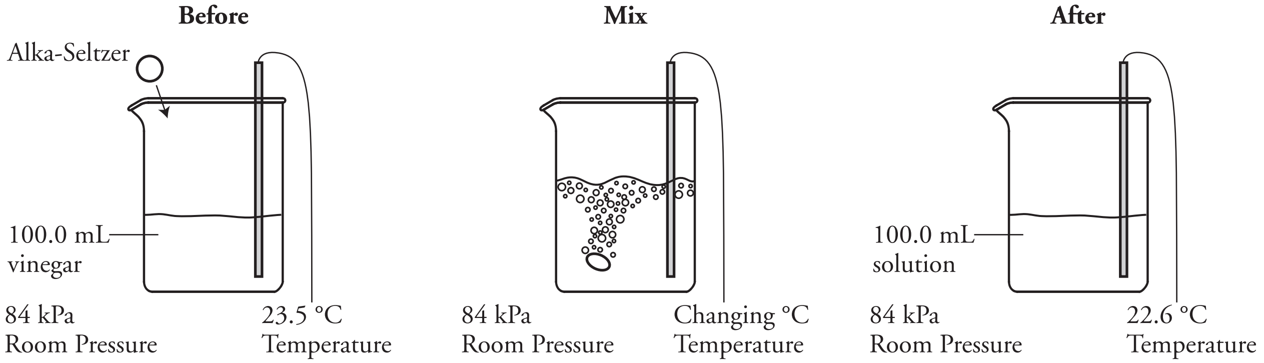
Fundamentals of Experimental Design

What is measured during a controlled experiment?

Why?

Working in the science lab can be a lot of fun. Mixing random chemicals and burning stuff just to see what happens can be entertaining (and possibly dangerous), but it doesn't lead to anything helpful to the scientific community. In order to be helpful to the community, a researcher's work in the lab must be systematic. A researcher usually asks a question and then designs an experiment to investigate that question. In this activity you will identify different types of variables that will help you design controlled experiments.

Model 1 – Alka-Seltzer® and Vinegar



1. Briefly describe the reaction illustrated in Model 1 in one or more complete sentences.

2. Did the room pressure change as the reaction occurred? If yes, was there an increase or decrease?

3. What two pieces of evidence observed during the "mix" phase of the reaction suggest that a chemical change is taking place?

4. Did the solution temperature increase or decrease during the reaction?

Model 2 – Results of Alka-Seltzer® Experiment

	Number of Alka-Seltzer Tablets	Volume of Vinegar (mL)	Room Pressure (kPa)	Initial Temp (°C) (Vinegar Solution)	Final Temp. (°C) (Final Mixture)
Trial 1	1	100.0	84	23.5	22.6
Trial 2	2	100.0	84	23.5	21.5
Trial 3	3	100.0	84	23.5	20.4
Trial 4	4	100.0	84	23.5	19.2
Trial 5	5	100.0	84	23.5	18.1

5. Which trial in the Model 2 data table corresponds to the reaction illustrated in Model 1?

6. Consider the five trials that produced the data in Model 2.
   a. What variable was purposefully changed in the experiment?

   b. What variable changed as a result of changing the variable listed in part *a*?

7. What variable(s) shown in the Model 2 data table remained constant among all the trials?

Model 3 – Boiling Points of Alcohols

Alcohol Name	Formula	Number of Carbons	Volume of Alcohol (mL)	Boiling Point (°C)	Room Pressure (kPa)
Methanol	CH_3OH	1	75	64.7	101
Ethanol	CH_3CH_2OH	2	75	78.4	101
Propanol	$CH_3CH_2CH_2OH$	3	75	97.1	101
Butanol	$CH_3CH_2CH_2CH_2OH$	4	75	117.7	101
Pentanol	$CH_3CH_2CH_2CH_2CH_2OH$	5	75	137.9	101

8. Describe the similarities and differences in the five alcohols used in the Model 3 experiment.

9. Consider the experiment that produced the data in Model 3.
   a. What variable was purposefully changed in the experiment?

   b. What variable changed as a result of changing the variable listed in part *a*?

10. What variable(s) in the Model 3 data table remained constant among all the trials?

STOP

Read This!

When designing an experiment, you need to consider three types of variables. The **independent variable** is changed by the experimenter by design. This variable is sometimes called the "manipulated variable." The **dependent variable** is what changes as a result of the change in the independent variable. This variable is sometimes called the "responding variable." In some cases more than one dependent variable is considered. The third category involves **controlled variables**. These are variables that you think might change the outcome of the experiment, but since you are not studying them, you need to keep them constant in each trial.

11. Identify the independent, dependent, and controlled variables for the experiments that produced the data shown in Model 2 and Model 3.

Model Experiment	**Variables**		
	Independent	**Dependent**	**Controlled**
Alka-Seltzer® and Vinegar			
Boiling Points of Alcohols			

Read This!

A well-written research question states the independent and dependent variables for an experiment. For example, a student investigated the effect of the deicer, magnesium chloride, on vegetation on the sides of highways. Her research question was, "What is the effect of magnesium chloride solution concentration on the growth of rye grass?"

12. Write a research question, using the format suggested in the *Read This!* box, for the experiments in Models 2 and 3.

Alka-Seltzer® and Vinegar —

Boiling Points of Alcohols —

13. A student wonders, "Will changing the volume of alcohol in a boiling point experiment change the boiling point of the liquid?" Identify the variables that should be considered in this experiment.

Independent	**Dependent**	**Controlled**

Extension Questions

14. Many experiments designed to investigate the reaction of Mentos® with Diet Coke® have been documented on YouTube. Design and write an experiment that uses the knowledge gained in this activity to investigate this reaction. Include a research question; the independent, dependent and controlled variables; and a simple procedure.

15. Scientists may design an experiment with a **control group**, which is a set of organisms or samples that do NOT receive the treatment (the independent variable) that is being tested. Scientists can then compare normal changes in organisms or samples with those that might have occurred because of the treatment. The idea of a "control group" is not the same as a "controlled variable." Suppose a scientist is doing an experiment to determine the effect of a cancer drug on mice with lymphoma.

    a. What are some of the variables the scientist should control in the experiment?

    b. Describe the control group for this experiment.

Organizing Data

How is data displayed to make it meaningful?

Why?

Scientists rely on data to describe nature and uncover relationships. The raw data—measurements taken in the lab—are most useful when they are organized in a way that makes the relationships clear. In this activity you will explore two common ways that scientists organize data to help in analysis.

Model 1 – Copper Samples

Group Number	Volume (cm^3)	Mass (g)	Substance
1	2.0	17.92	Copper
2	6.0	50.89	Copper
3	10.0	93.45	Copper
4	8.0	79.30	Copper
5	14.0	125.44	Copper
6	4.0	39.80	Copper
7	12.0	103.85	Copper

Room Temperature: 21.7 °C

1. What substance were the students working with to obtain the data in Model 1?

2. What variables did the students measure to produce the data in Model 1?

3. Briefly describe an experiment that the class might have done on the day that the data in Model 1 was collected. Discuss your answer with your group members to be sure there is consensus.

4. Consider the data in Model 1.
    a. Which variable was the **independent variable** in the experiment, and why do you think it was the independent variable?

    b. Which variable was the **dependent variable** in the experiment, and why do you think it was the dependent variable?

    c. List two **controlled variables** in the experiment?

STOP

5. Consider the data in Model 1.
   a. How is the data organized?

   b. Is the table in Model 1 organized in a way that helps determine a relationship between the independent and dependent variables in the experiment? Explain.

6. Propose a better way to organize the data in Model 1, and transcribe the data into the table below.

Group Number	**Volume (cm^3)**	**Mass (g)**	**Substance**

7. The data table in Question 6 should allow you to state a relationship between the variables involved in the class's experiment. Complete the following statement:

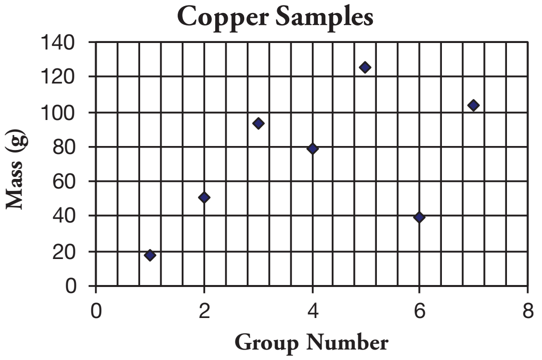
   As the volume of copper increases, the mass of copper ________________________________.

Read This!

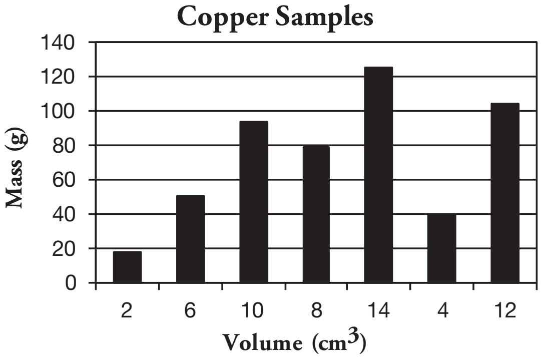
When scientists design an experiment they are usually looking for a cause-and-effect relationship between the independent variable and the dependent variable. Therefore, organizing the data by the independent variable is the easiest way to reveal a relationship. When the data is not organized, the relationships are not apparent.

Model 2 – Graphs for Copper Data

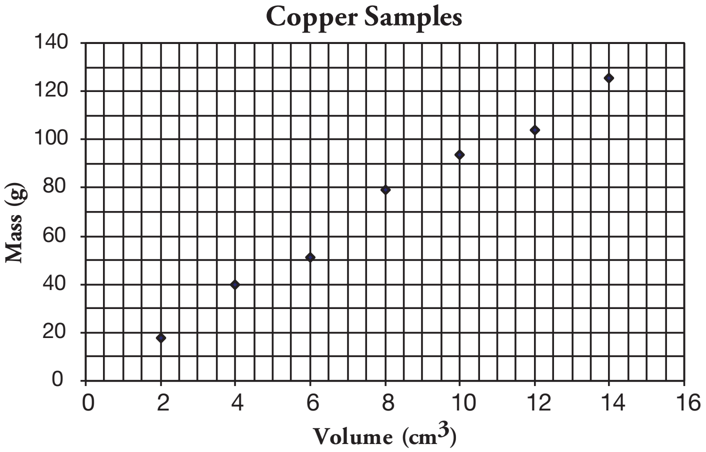
Graph A



Graph B



Graph C



8. Identify each of the graphs in Model 2 as a bar graph or a scatter plot.

9. One of the data points in graph B indicates that a volume of 8 cm^3 has a mass of 80 g. Which other graph in Model 2 shows this same data?

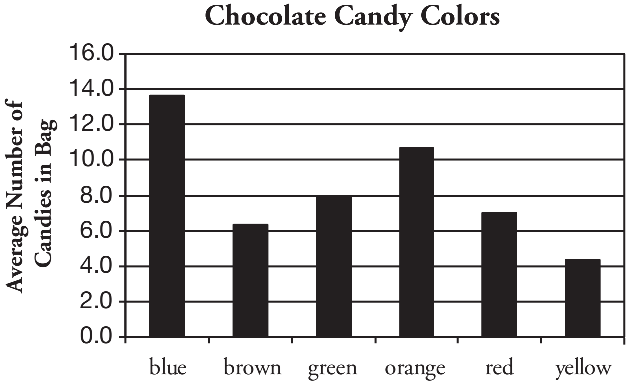
10. Of the three graphs in Model 2, which illustrates the relationship between the variables that you stated in Question 7 most clearly?

Read This!

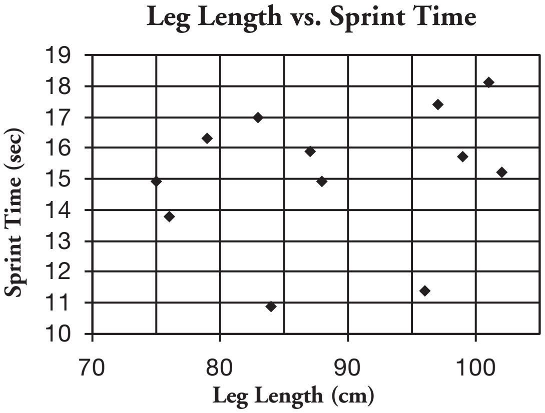
Scientists use graphs to clearly illustrate whether or not there is a relationship between variables. In most cases a scatter plot is used. Bar graphs are sometimes used if the independent variable is limited to specific numeric values (where the values in-between are not possible) or is non-numeric. A special type of bar graph called a histogram is used in cases where the scientist wants to show how often something happens.

Model 3 – More Examples of Graphs

Graph D



Graph E



11. Identify the independent variable and dependent variable for each of the graphs in Model 3.

	Graph D	Graph E
Independent Variable		
Dependent Variable		

12. Match the experimental questions below to the appropriate graph from Model 3.
    a. "Is the number of candies in a bag of chocolates dependent on the color of the candy?"
    Graph _____
    b. "Does the length of a person's leg affect the time it takes them to sprint 60 yards?"
    Graph _____

13. Why was the data for Graph D plotted in a bar graph?

14. Using the graphs in Model 2 and Model 3 as examples of proper graphs, identify the axis (*x* or *y*) where you would usually plot the independent variable.

15. For each of the following experiments, choose “scatter plot” or “bar graph” as the most appropriate way to display the data. Justify your answer.

    a. Students heated oil on a hot plate at the #4 setting for different amounts of time. They wanted to answer the question “How long do you need to heat an oil bath to reach a given temperature?”

Volume Oil (mL)	**Hot Plate Setting**	**Initial Temp. of Oil (°C)**	**Time Heated (min)**	**Final Temp. of Oil (°C)**
250	#4	21	0	21
250	#4	21	5	30
250	#4	21	10	38
250	#4	21	15	47
250	#4	21	20	57

    b. Students measured the height of each student in class. They wanted to answer the question “What is the most common height among 10th grade students?”

Height Range	**Number of Students**
under 4′ 0″	1
4′ 1″ to 4′ 6″	3
4′ 7″ to 5′ 0″	5
5′ 1″ to 5′ 6″	9
5′ 7″ to 6′ 0″	3
over 6′ 0″	1

    c. The Fish and Wildlife agency measured the size of Pacific salmon for 1 year and recorded the average weight for each species.

Salmon Species	**Average Weight (lbs)**
King	15
Sockeye	8
Silver	12
Chum	15
Humpback	5

    d. The National Oceanic and Atmospheric Administration measured the pressure of the atmosphere at various altitudes.

Altitude (m)	**Atmos. Pressure (atm)**	**Altitude (m)**	**Atmos. Pressure (atm)**
0	1.000	16,132	0.100
2750	0.750	30,901	0.010
5486	0.500	48,467	0.001
8376	0.333		

STOP

16. Choose one of the data sets in Question 15 that you selected as appropriate for a scatter plot and graph it here. Remember to label the axes.

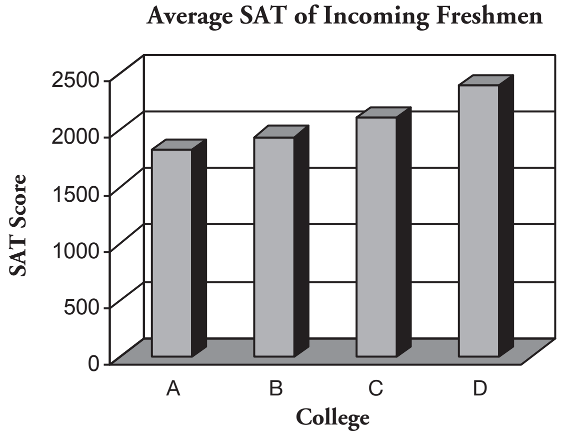
17. Choose one of the data sets in Question 15 that you selected as appropriate for a bar graph and graph it here. Remember to label the axes.

18. Send one representative of your group to another table to share the two graphs constructed in Questions 16 and 17. Does the other group agree that your graphs are properly constructed? If not, what adjustments do you think need to be made?

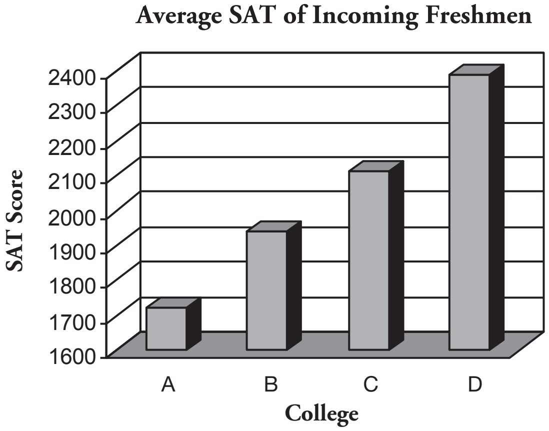
Extension Questions

Model 4 – SAT Scores

Graph F



Graph G



19. Describe the independent and dependent variables for the data that is displayed in Graphs F and G in Model 4.

20. When you look at Graph F, what message is communicated by the relative lengths of the bars to prospective students about College D's average SAT scores compared to the other three schools?

21. When you look at Graph G, what message is communicated by the relative lengths of the bars to prospective students about College D's average SAT scores compared to the other three schools?

22. For each of the graphs in Model 4, estimate the average score for each college represented by the height of the bar. Is the data being displayed in the two graphs the same or different? Support your answer with evidence from the graph.

23. A student takes a quick look at Graph G and says "Based on the size of these bars, it looks to me as though College D had entering freshman with SAT scores nearly four times higher than College A." Explain to this student what mistake he has made in processing the information presented in Graph G.

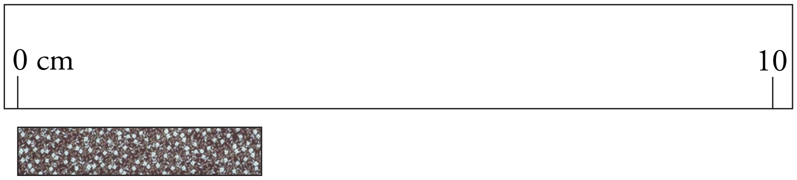
Significant Digits and Measurement

What digits are significant when recording a measurement?

Why?

Scientists do a lot of measuring. When scientists use an instrument (such as a ruler, graduated cylinder, spectrophotometer or balance) to measure something, it is important to take full advantage of the instrument. However, they can't cheat and record a better measurement than the instrument is capable of. There is an understanding among scientists of the proper way to record valid measurements from any instrument. When you are the scientist, you must record data in this way. When you are reading other scientists' work, you must assume they recorded their data in this way.

Model 1 – Ruler A



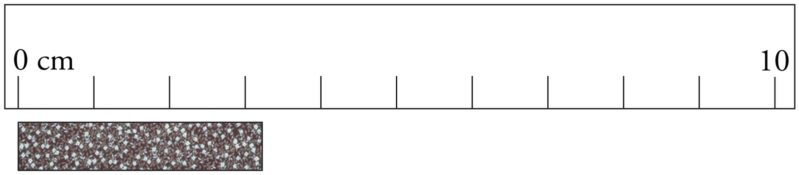
Susan	3 cm
Maya	2 cm
Jonah	2.5 cm
Tony	3.00 cm
Emily	3¼ cm
Dionne	3.33 cm

1. What distances can you be certain of on the ruler in Model 1?

2. Six students used the ruler in Model 1 to measure the length of a metal strip. Their measurements are shown at the right. Were all of the students able to agree on a single value (1, 2, 3…) for any digit (ones place, tenths place, etc.) in the measurement? If yes, which value and digit did they agree on?

3. The ruler in Model 1 is not very useful, but a measurement can be estimated. Discuss in your group how each student might have divided up the ruler "by eye" in order to get the measurement that he or she recorded.

Model 2 – Ruler B



Susan	3.2 cm
Maya	3.1 cm
Jonah	3.3 cm
Tony	3 cm
Emily	3.25 cm
Dionne	3.20 cm

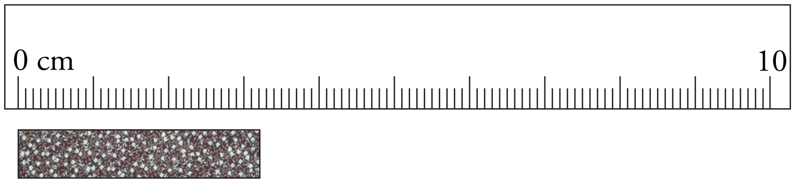
4. The students obtained a better ruler, shown in Model 2. What distances can you be certain of on this ruler?

5. Were the students able to agree on a single value (1, 2, 3…) for any digit (ones place, tenths place, etc.) in their measurements using the ruler in Model 2? If yes, what value in what digit did they agree on?

6. What feature of the ruler in Model 2 made it possible for the students to agree on a value in that digit?

7. There will always be uncertainty in any measurement. This causes variation in measurements even if people are using the same instrument. Compare the variation in the measurements made by the six students using the rulers in Models 1 and 2. Which ruler resulted in greater variation? Explain why that ruler caused more variation.

Model 3 – Ruler C



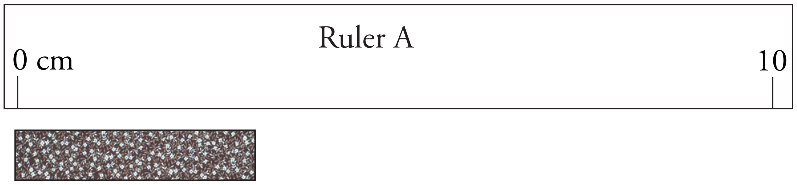
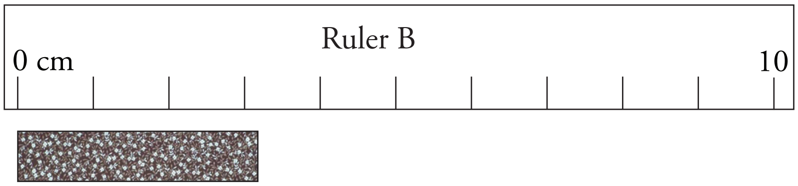
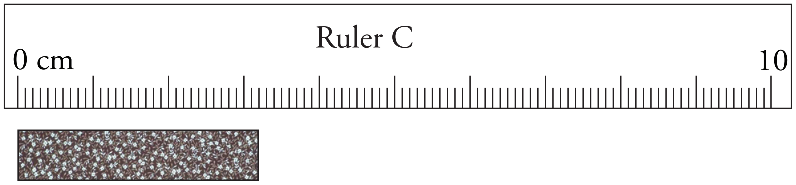
Susan	3.21
Maya	3.20 cm
Jonah	3.22 cm
Mark	3.2 cm
Emily	3.215 cm
Dionne	3.205 cm

8. The students obtained an even better ruler, shown above in Model 3.
   a. Were the students able to agree on a single value for any of the digits in their measurements using the new ruler? If yes, what value(s) did they agree on in which digits?
   b. What feature of the ruler in Model 3 made it possible for the students to agree on the values in those digits?

Read This!

When humans use measuring instruments, variation is expected. Everyone will estimate differently between marks on the instrument. On the other hand, digits that are certain (based on marks on the instrument) should not vary from person to person.

Model 4 – Valid Measurements

	Valid Measurements	Invalid Measurements
	3 cm 2 cm	2.5 cm 3.00 cm 3¼ cm 3.33 cm
	3.2 cm 3.1 cm 3.3 cm	3 cm 3.25 cm 3.20 cm
	3.21 cm 3.22 cm 3.20 cm	3.2 cm 3.215 cm 3.205 cm

9. The measurements taken in Models 1–3 have been combined in Model 4. The measurements that follow the rules of measurement agreed upon by scientists are in the "Valid Measurements" column. Those that do not follow the rules are in the "Invalid Measurements" column. For each valid measurement shown in Model 4, draw a square around the certain digits (if any) and circle the digits that were estimated (if any).

10. Based on the examples in Model 4, circle the best phrase to complete each sentence below.

    a. In a valid measurement, you record (zero, one, two) estimated digit(s).

    b. In a valid measurement, the estimated digit is the (first digit, second to last digit, last digit) in the measurement.

    c. In a valid measurement, the estimated digit corresponds to (the largest marks, the smallest marks, one tenth of the smallest marks) on the instrument.

11. Using Ruler B from Model 4, Tony recorded a measurement of 3 cm. Explain why this was an invalid measurement.

12. Using Ruler B from Model 4, Dionne recorded a measurement of 3.20 cm, which was invalid. But when Maya made the same measurement using Ruler C, it was considered valid. Explain why the zero was acceptable when using Ruler C, but not when using Ruler B.

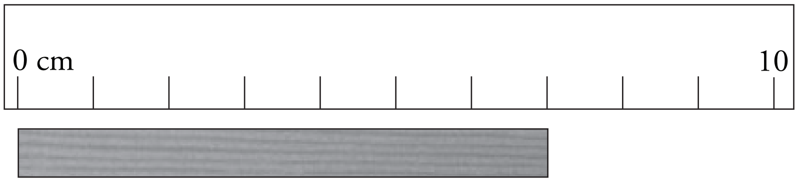
13. A student recorded the length of a test tube as 5.0 cm. Which ruler in Model 4 was the student using? Explain.

14. In Model 4, Ricky recorded his measurement 3.19 cm using Ruler C. His classmates thought he was wrong because his second digit was not "2." However, Ricky's recorded measurement is perfectly valid. Explain.

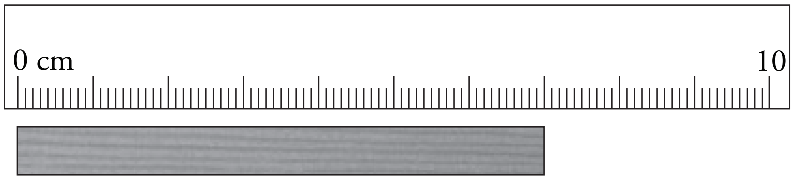
Read This!

When a measurement is recorded properly, all of the digits that are read directly (certain) and one estimated (uncertain) digit are called **significant digits**. The number of allowable significant digits is determined by the marks or gradations of the instrument. Sometimes a "0" is the estimated digit and must be recorded.

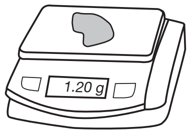
15. Record the length of the wooden splint to the proper number of significant digits.



16. Record the length of the wooden splint to the proper number of significant digits.



Extension Questions

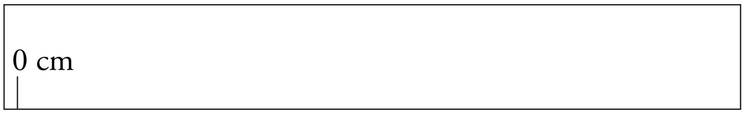


17. When using an electronic device, such as an electronic balance, the measurement displayed on the screen is assumed to have one estimated digit included. In fact, you'll often see the estimated digit changing rapidly, because there is fluctuation in the estimate. Explain why it is important to record the zero in the measurement shown to the right.

18. Consider a 1000-mL graduated cylinder with marks every 100 mL.
    a. A student records the volume of liquid in the cylinder as 750 mL. Is this a correct measurement? Explain.

    b. Are all of the digits in the described measurement of 750 mL significant? Explain.

19. A student properly records the length of a block as 120 cm. Draw the markings on the ruler that was used to measure the block.



Significant Zeros

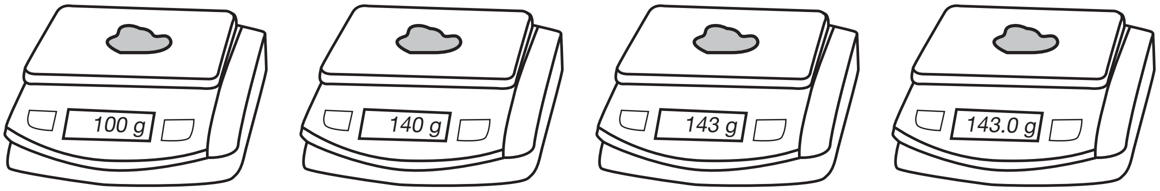
Which zeros are significant in a measurement, and which are simply important?

Why?

When working with measurements, it is important to know which digits in the measurement are significant and which are not. Non-zero digits are always significant. However, zeros can be tricky; some are significant, others are not. This activity will help you learn the rules for determining whether a zero digit is significant or not.

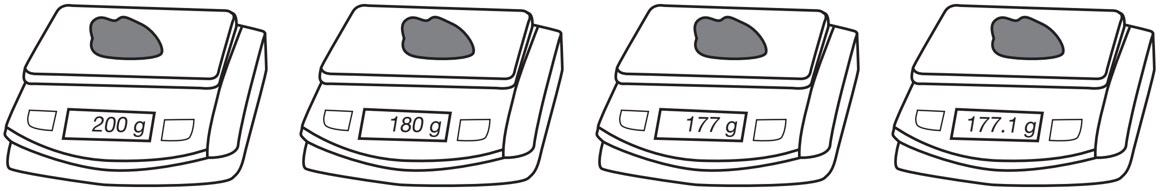
Model 1 – Mass of Rocks

Sample A



Econo-Balance Good Balance Balance Pro Exacto-Balance

Sample B



Econo-Balance Good Balance Balance Pro Exacto-Balance

1. For each balance in Model 1, circle the phrase below that best describes how closely the mass can be determined with that balance.

Econo-Balance	estimated to the nearest 100 g	estimated to the nearest 10 g	estimated to the nearest 1 g	estimated to the nearest 0.1 g
Good Balance	estimated to the nearest 100 g	estimated to the nearest 10 g	estimated to the nearest 1 g	estimated to the nearest 0.1 g
Balance Pro	estimated to the nearest 100 g	estimated to the nearest 10 g	estimated to the nearest 1 g	estimated to the nearest 0.1 g
Exacto-Balance	estimated to the nearest 100 g	estimated to the nearest 10 g	estimated to the nearest 1 g	estimated to the nearest 0.1 g

2. Which of the four balances in Model 1 is the best quality instrument? Explain.

3. Rock C is placed on the Econo-Balance. The balance reads 200 g.
   a. Does rock C have a mass larger, smaller or the same as sample A, or is it impossible to tell? Explain your reasoning.

   b. Does rock C have a mass larger, smaller or the same as rock B, or is it impossible to tell? Explain your reasoning.

4. The mass of rock C is then measured using the other three balances. The results are shown below.

Econo-Balance	200 g	Balance Pro	177 g
Good Balance	180 g	Exacto-Balance	177.0 g

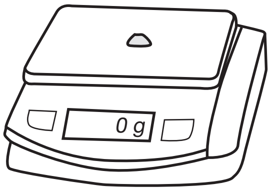
   a. Based on this additional information, does rock C have a mass larger, smaller or the same as rock B, or is it impossible to tell? Explain your reasoning.

   b. Explain why the zero in the Exacto-Balance reading provides important information about the mass of rock C, but the zero in the Good Balance reading does not.

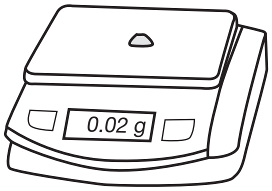
STOP

Model 2 – Mass of Pebbles

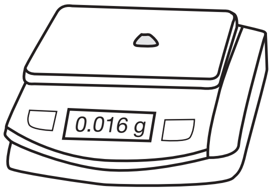
Pebble A



Balance Pro

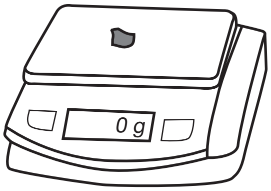


Centi-Balance

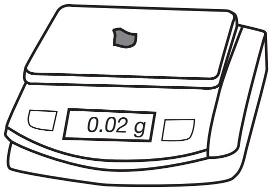


Super Balance

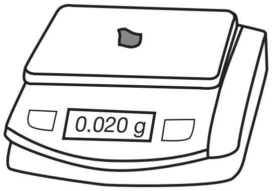
Pebble B



Balance Pro



Centi-Balance



Super Balance

5. For each balance in Model 2, write a phrase to describe how closely the mass of an object can be determined using that balance. The first one is done for you.

   Balance Pro: Estimated to the nearest 1 gram.

   Centi-Balance:

   Super Balance:

6. Pebble A and pebble B both have a mass of 0 g on the Balance Pro in Model 2. Do these pebbles really have no mass? If no, explain why the balance has this reading.

7. Which balance is sensitive enough to determine if pebble A has a mass larger or smaller than pebble B?

8. The mass reading of pebble B from the Super Balance is 0.020 g. This value is very close, but different than, the mass reading for pebble A on that same balance. Determine which of the three zeros in the mass reading for pebble B is the most significant in terms of determining whether pebble B has a different mass than pebble A, and circle the zero below.

   Mass pebble B = 0.020 g

Model 3 – Types of Zeros

200 g	180 g	140 g	100 g	**Placeholder Zeros**
0.02 g	0.016 g			
$0.02\underline{0}$ g	$177.\underline{0}$ g	$143.\underline{0}$ g		**Significant Zeros** (underlined)

9. Model 3 shows several of the measurements from Model 1 and Model 2. The zeros in those measurements are categorized into two types. List the two types.

10. Consider the term "placeholder" as it is used in the English language. Discuss two examples of this term in your group, and summarize them here.

11. Describe the two types of placeholder zeros shown in Model 3.

12. If you removed a placeholder zero from a number, would the numeric value of the number change?

13. Describe the location of significant zeros in a number relative to the decimal point.

14. If you removed a significant zero from the end of a number, would the numeric value of the number change?

Read This!

Placeholder zeros are very important—they help put the decimal point in the correct spot. However, they are ***not*** significant when it comes to the certainty of a measurement. In other words, placeholder zeros cannot be a certain or estimated digit in a measurement. They may show up in calculations however. For example, if you convert 29.3 m to 29,300 mm, the zeros that you add to the measurement were not read from the measuring instrument.

15. Determine if the zeros in the measurements below are significant or not. If a zero is significant, underline it.

a. 650 m *b.* 42.0 s *c.* 7000 L

d. 3.000 kg *e.* 0.008 mL *f.* 0.00560 cm

16. Here are five rules for determining which digits in a measurement are significant. Match each rule to a set of examples in the table below. The significant digits in each example are underlined.

Rule 1: All non-zero numbers are significant.

Rule 2: Sandwiched zeros (those that occur between two significant digits) are significant.

Rule 3: Zeros that are only placeholders for a decimal are not significant.

Rule 4: Zeros at the end of a number that also contains a decimal are significant.

Rule 5: Exact numbers (no doubt or uncertainty in the value) may be thought of as having an *infinite* number of significant digits. These include numbers that were counted or are defined values (*i.e.,* conversion factors).

<table>
<tr><td>Set A
$\underline{105}$ cm, $0.\underline{402}$ g,
$\underline{4003.7}$ mL, $\underline{10.0}$ s</td><td>Set B
$\underline{63}00$ mL, $\underline{4}00$ m,
$0.00\underline{4}$ g, $0.0\underline{97}$ kg</td><td>Set C
$\underline{30.40}$ m, $\underline{1.620}$ s, $0.0\underline{400}$ L</td></tr>
<tr><td>Set D
$\underline{589}$ s, $\underline{45}$ kg, $\underline{5.68}$ g, $\underline{0.452}$ L</td><td colspan="2">Set E
1 dozen = $\underline{12}$
1 m = $\underline{100}$ cm
$\underline{29}$ students on a bus</td></tr>
</table>

17. In the measurements below, the significant digits are underlined. Determine the rule(s) that were used to decide which digits were significant, and which were not significant.

a. $0.\underline{420}$ g *b.* $\underline{21}00$ g *c.* $\underline{51.0}$ m

d. $\underline{590}$ students *e.* $\underline{5,200.0}$ g *f.* $\underline{602}0$ mg

18. Underline all of the significant digits in the following values.

a. 94,000 m *b.* 7200 apples *c.* 0.004380 g

d. 400.0 kg *e.* 80,050 s *f.* 1000 g = 1 kg

Extension Questions

Model 4 – Scientific Notation (Significant digits are underlined.)

A. $\underline{3} \times 10^{4}$ m = $\underline{3}0{,}000$ m

$\underline{3.00} \times 10^{4}$ m = $\underline{30}{,}\underline{0}00$ m

B. $\underline{7} \times 10^{-3}$ kg = $0.00\underline{7}$ kg

$\underline{7.00} \times 10^{-3}$ kg = $0.00\underline{700}$ kg

C. $\underline{4.1} \times 10^{4}$ m = $\underline{41}{,}000$ m

$\underline{4.10} \times 10^{4}$ m = $\underline{41}{,}\underline{0}00$ m

D. $\underline{9.42} \times 10^{-3}$ kg = $0.00\underline{942}$ kg

$\underline{9.420} \times 10^{-3}$ kg = $0.00\underline{9420}$ kg

19. The measurements in Model 4 are written in both scientific notation and expanded notation.

    Copy one example of each below.

    Scientific notation Expanded notation

20. Refer to the two measurements in set A of Model 4.

    a. Do the two measurements have the same numeric value?

    b. Were the two measurements made using the same instrument? Explain.

21. Look at all of the measurements in Model 4. When a number in scientific notation is changed to expanded notation, are any of the added zeros significant? Give two examples to support your answer.

22. When a number in scientific notation contains a significant zero, is that zero also significant in the expanded notation? Give two examples to support your answer.

23. Write each of the measurements below in expanded notation and underline the significant digits.

    a. 5.0780×10^{6} g =

    b. 4.800×10^{-4} L =

    c. 0.7200×10^{4} mm =

    d. 3700×10^{-3} cm =

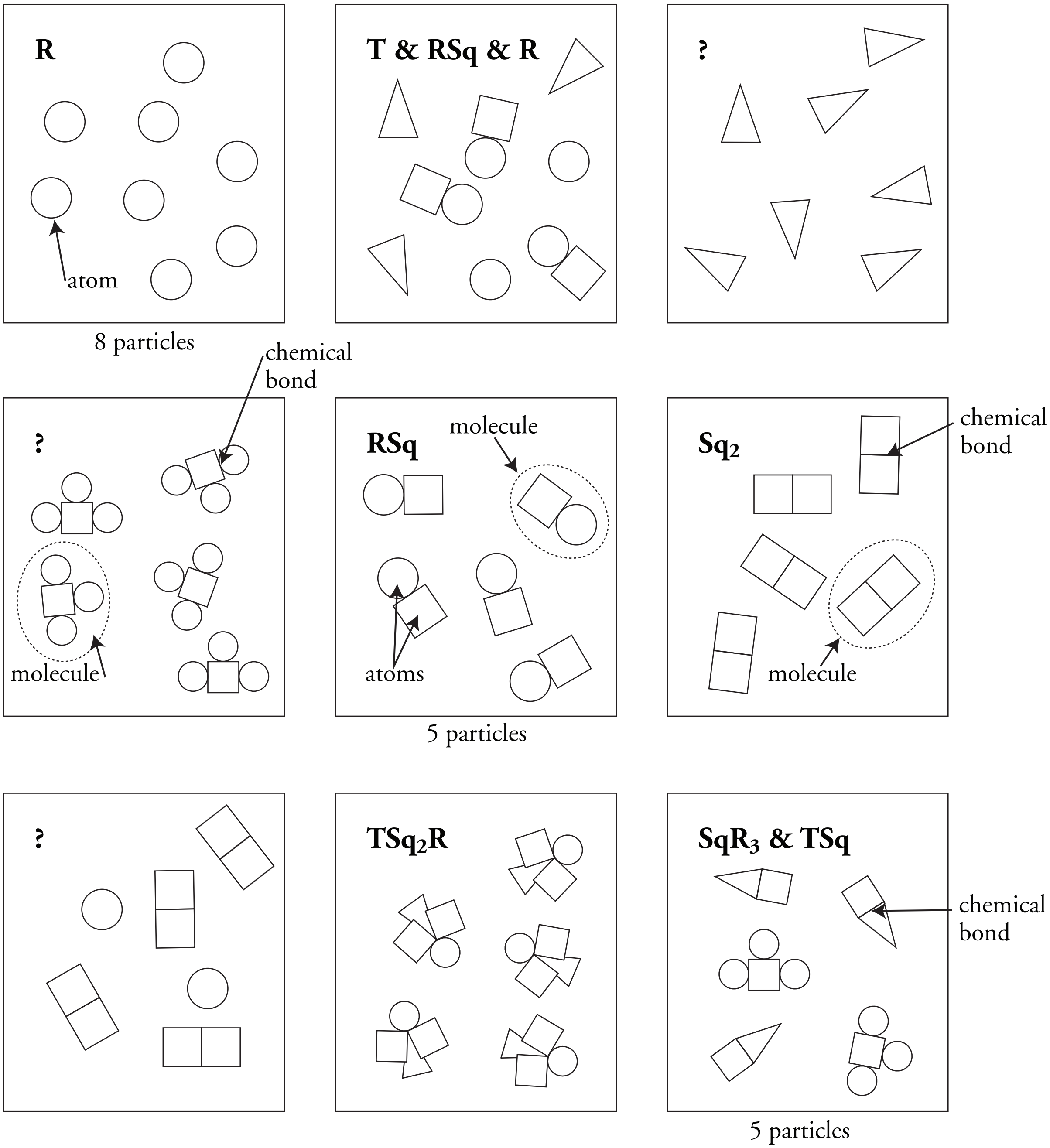
Classification of Matter

How do atoms combine to make different types of matter?

Why?

Look at the things in this room. They are all matter. That matter may be pure or it may be a mixture. Can you tell by looking at it? What if you looked at it under a microscope? Then could you tell? Something that looks pure may not really be pure. It depends on what type of particles an object or substance is made of. In this activity we will explore how the smallest chemical units of matter determine whether something is classified as an element, a compound, or a mixture.

Model 1 — Atoms, Particles, and Molecules



1. Locate the circled molecule of **RSq** in Model 1.
   a. Find a second **RSq** molecule and circle it.
   b. How many atoms are in a molecule of **RSq**?

2. Find and circle a molecule of **TSq$_2$R** in Model 1.
   a. How many different types of atoms are found in a molecule of **TSq$_2$R**?

   b. How many Sq atoms are in a molecule of **TSq$_2$R**?

3. Locate the drawing labeled **SqR$_3$ & TSq** in Model 1.
   a. How many different types of atoms are found in the sample of **SqR$_3$ & TSq**?

   b. How many different types of molecules are found in the sample of **SqR$_3$ & TSq**?

4. When two atoms are touching in the drawings of Model 1, what is holding the atoms together?

5. As a group, discuss the following questions and record your answers:
   a. Can a *particle* be a single atom?

   b. Can a *particle* be a molecule?

   c. How many particles are in the drawing representing **T & RSq & R** in Model 1?

   d. What is your group's definition of the word "particle" as it is used in chemistry?

6. Compare the codes listed at the top of each drawing in Model 1 with the shapes in that box.
   a. What do the letters **R**, **Sq,** and **T** in the codes represent?

   b. What do the small numbers (subscripts) in the codes represent?

   c. When atoms are touching, how is that communicated in the code?

   d. What is the common characteristic of the samples in which an ampersand (&) is used?

   e. In Model 1 there are three drawings that are labeled with a question mark. Write codes to properly label these drawings.

7. Appoint one group member to cut apart Model 1 to separate the nine drawings. As a team, sort the drawings into two groups—one group where all the particles in the drawing are identical, and a second group in which the drawings contain more than one type of particle.

Read This!

Matter is classified as a **pure substance** when all of the particles are identical. Matter is classified as a **mixture** if there are different types of particles present.

8. Identify which drawings from Question 7 are pure substances and which are mixtures. List the codes for the drawings in the appropriate places below.

Pure Substances		**Mixtures**
________________	________________	________________
________________	________________	________________
________________	________________	________________

9. How are the codes (chemical formulas) for pure substances different from those for mixtures?

10. As a team, take the set of pure substances drawings from Question 8 and sort them into two new groups, those containing only one type of atom and those with two or more types of atoms.

Read This!

Elements are defined as pure substances made from only one type of atom. **Compounds** are defined as pure substances made from two or more types of atoms.

11. Identify which drawings from Question 10 are elements and which are compounds. List the codes for the drawings in the appropriate places below.

Elements	**Compounds**
________________	________________
________________	________________
________________	________________

12. How are the codes (chemical formulas) for elements different from those for compounds?

13. Use what you have just learned about chemical formulas to identify each of the following as an element, a compound or a mixture.

a. Br_2 *b.* $NaHCO_3$ *c.* $C_6H_{12}O_6$ & H_2O

d. Cu & Zn *e.* CO_2 *f.* Al

14. Explain the difference between:
    a. An atom and an element.

    b. A molecule and a compound.

Extension Questions

15. It is often useful to separate matter. Physical methods of separation (filtering, distillation) do not require a chemical change. In other words, no chemical bonds are broken or formed during the separation. Chemical methods of separation (decomposition, electrolysis) require a chemical change. In other words, chemical bonds are broken and/or formed during the separation.

    a. Is straining cooked pasta from water a physical or chemical separation?

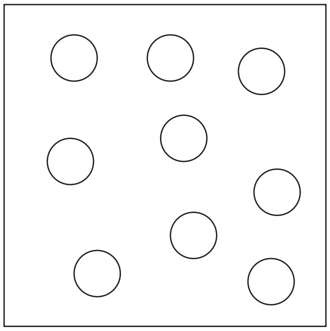
    b. Is using a fuel cell to separate water into hydrogen and oxygen a physical or chemical separation?

    c. Which type(s) of matter (mixtures/compounds/elements) could be separated by physical methods?

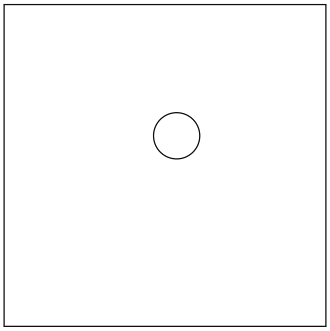
    d. Which type(s) of matter (mixtures/compounds/elements) would need to be separated by chemical methods?

16. Students in a chemistry course were asked the following question on a unit exam: "Draw a diagram representing an element using circles as atoms."

    a. The following diagrams represent two typical answers given by students. Which drawing is the best representation of an element? Explain.



Drawing A



Drawing B

    b. Imagine that the atom in Drawing B had been removed by physical separation from one of the substances in Model 1. What substances could have been the source of the atom in Drawing B?

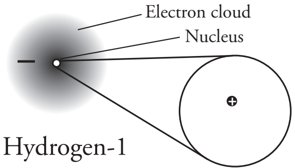
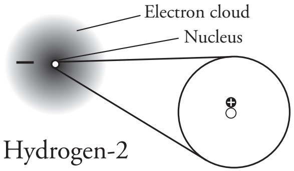
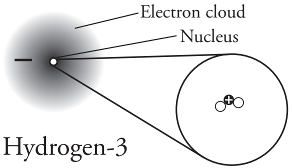
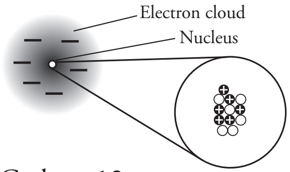
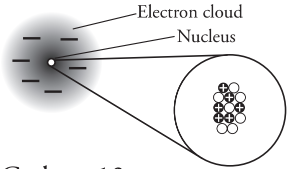
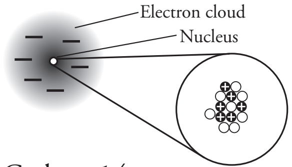
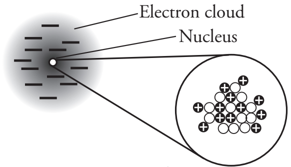
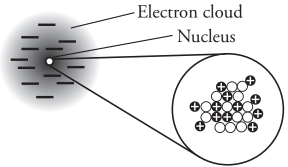
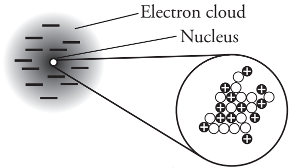
Isotopes

Are all atoms of an element alike?

Why?

The following activity will help you learn the important structural characteristics of an atom. How do we classify atoms? How does the combination of subatomic particles affect the mass and charge of an atom? What are isotopes? This is just a sampling of what we will address. Throughout this activity you will want to keep both Model 1 and a periodic table handy.

Model 1

Isotopes of Hydrogen			
Symbol	$^{1}_{1}\mathrm{H}$	$^{2}_{1}\mathrm{H}$	$^{3}_{1}\mathrm{H}$
Atomic Diagram with Name	 Hydrogen-1 (protium)	 Hydrogen-2 (deuterium)	 Hydrogen-3 (tritium)
Number of Protons ⊕			
Number of Neutrons ○			
Isotopes of Carbon			
Symbol	$^{12}_{6}\mathrm{C}$	$^{13}_{6}\mathrm{C}$	$^{14}_{6}\mathrm{C}$
Atomic Diagram with Name	 Carbon-12	 Carbon-13	 Carbon-14
Number of Protons ⊕			
Number of Neutrons ○			
Isotopes of Magnesium			
Symbol	$^{24}_{12}\mathrm{Mg}$	$^{25}_{12}\mathrm{Mg}$	$^{26}_{12}\mathrm{Mg}$
Atomic Diagram with Name	 Magnesium-24	 Magnesium-25	 Magnesium-26
Number of Protons ⊕			
Number of Neutrons ○			

1. Refer to Model 1. What subatomic particles do the following symbols represent in the Atomic Diagrams?

   ▬ ⊕ ○

2. Complete the table in Model 1 by counting the protons and neutrons in each atomic diagram. Divide the work evenly among group members.

3. Find the three elements shown in Model 1 on your periodic table.
   a. What whole number shown in Model 1 for each element is also found in the periodic table for that element?

   Hydrogen — Carbon — Magnesium — *1*

   b. The whole number in each box of the periodic table is the atomic number of the element. What does the **atomic number** of an element represent?

   c. Refer to the isotope symbols in Model 1. Relative to the atomic symbol (H, C, or Mg), where is the atomic number located in the isotope symbol?

4. Refer to your periodic table.
   a. How many protons are in all chlorine (Cl) atoms?

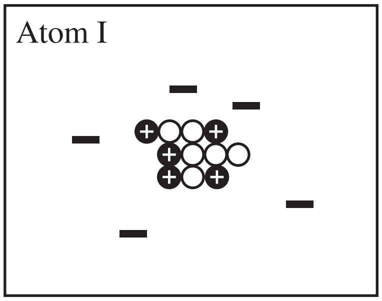
   b. A student says "I think that some chlorine atoms have 16 protons." Explain why this student is not correct.

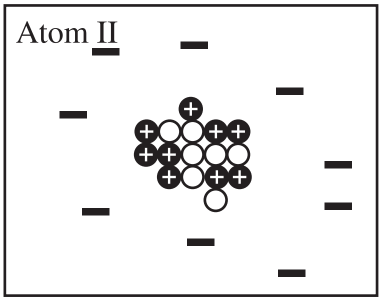
5. Refer again to Model 1. In the isotope symbol of each atom, there is a superscripted (raised) number. This number is also used in the name of the atom (*i.e.,* carbon-12). It is called the **mass number**.
   a. How is the mass number determined?

   b. Why is this number called a "mass" number?

6. Fill in the table for Atom I and Atom II shown below.

	Atom I	**Atom II**
Number of Protons		
Number of Neutrons		
Mass Number		





7. Refer to Model 1.

   a. Which corner of the isotope symbol contains the mass number?

   b. How is the mass number of an isotope expressed in the name of an atom?

8. Write an isotope symbol (similar to those in Model 1) for each of the atoms in Question 6.

9. Write the name of the atom (similar to those in Model 1) for each of the atoms in Question 6.

10. Fill in the following table.

Isotope Symbol	$^{40}_{19}\text{K}$	$^{18}_{9}\text{F}$	
Atomic Number			16
Mass Number			
Number of Protons			
Number of Neutrons			15

11. Consider the examples in Model 1.

    a. Do all isotopes of an element have the same atomic number? Give at least one example or counter-example from Model 1 that supports your answer.

b. Do all isotopes of an element have the same mass number? Give at least one example or counter-example from Model 1 that supports your answer.

12. Considering your answers to Question 11, write a definition of **isotope** using a grammatically correct sentence. Your group must come to consensus on this definition.

STOP

13. Consult the following list of isotope symbols: $^{204}_{82}\text{Pb}$, $^{82}_{35}\text{Br}$, $^{78}_{35}\text{Br}$, $^{208}_{82}\text{Pb}$, $^{204}_{78}\text{Pt}$, $^{205}_{82}\text{Pb}$.

    a. Which of the atoms represented by these symbols are isotopes of each other?

    b. Which part(s) of the isotope symbol was the most helpful in answering part *a* of this question?

Extension Questions

14. Determine the number of electrons in each of the atomic diagrams in Model 1.
    a. In a neutral atom, how does the number of electrons compare to the number of protons?

    b. Discuss why this relationship is important in making a "neutral" atom.

15. Refer to the hydrogen isotopes in Model 1. Each isotope has a special name derived from Latin (protium, deuterium, and tritium). What structural feature do these names refer to in the atom?

16. Can two atoms with the same mass number ever be isotopes of each other? Explain.

17. All models have limitations. What characteristics of Model 1 are inconsistent with your understanding of what atoms look like?

Ions

How are ions made from neutral atoms?

Why?

You have learned that not all atoms of an element are the same. Variation in the number of neutrons results in different isotopes of the element. In this activity we will explore another variation that can take place—the loss and gain of electrons. The exchange of electrons between atoms is a very common way for chemical change to take place. We will see it many times throughout the year.

1. Use Model 1 to complete the following table.

	Metal or Nonmetal	**Is the number of protons the same in the atom and the ion?**	**Is the number of neutrons the same in the atom and the ion?**	**Is the number of electrons the same in the atom and the ion?**	**Charge on the ion**
Lithium	metal				1+
Magnesium					2+
Aluminum		yes			3+
Fluorine				no	1–
Oxygen	nonmetal		yes	no	2–
Nitrogen					3–

2. Based on the table you completed in Question 1, what distinguishes a neutral atom from an ion?

3. Examine the isotope symbols in Model 1.

   a. Where is the ion charge located in the isotope symbol?

   b. Is a charge indicated on the neutral atoms? If yes, where is it located?

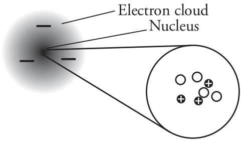
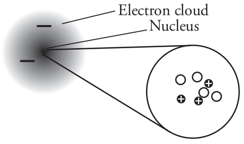
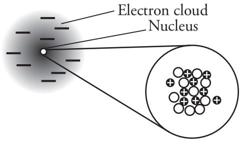
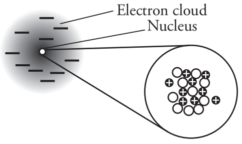
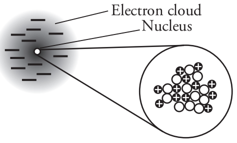
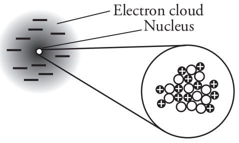
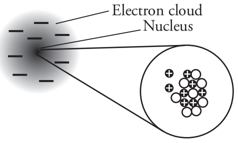
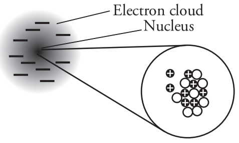
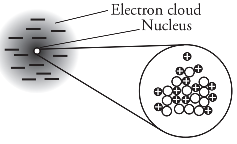
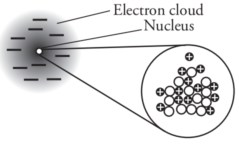
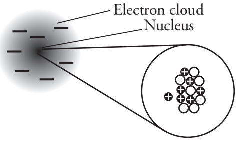
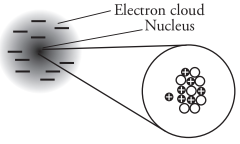
4. Which subatomic particle carries a positive charge?

5. Which subatomic particle carries a negative charge?

6. Propose a mathematical equation to calculate the charge on an ion from the number of protons and electrons in an ion. Confirm that your equation works using two positive ion examples and two negative ion examples from Model 1.

STOP

Model 1 – Atoms and Ions

	Neutral Atoms	**Ions**		**Neutral Atoms**	**Ions**
	Atom of Lithium	Ion of Lithium		Atom of Fluorine	Ion of Fluorine
Symbol	${}^{7}_{3}\mathrm{Li}$	${}^{7}_{3}\mathrm{Li}^{1+}$	**Symbol**	${}^{19}_{9}\mathrm{F}$	${}^{19}_{9}\mathrm{F}^{1-}$
Atomic Diagram			**Atomic Diagram**		
No. of Protons ⊕	3	3	**No. of Protons** ⊕	9	9
No. of Neutrons ○	4	4	**No. of Neutrons** ○	10	10
No. of Electrons ▬	3	2	**No. of Electrons** ▬	9	10
	Atom of Magnesium	Ion of Magnesium		Atom of Oxygen	Ion of Oxygen
Symbol	${}^{24}_{12}\mathrm{Mg}$	${}^{24}_{12}\mathrm{Mg}^{2+}$	**Symbol**	${}^{16}_{8}\mathrm{O}$	${}^{16}_{8}\mathrm{O}^{2-}$
Atomic Diagram			**Atomic Diagram**		
No. of Protons ⊕	12	12	**No. of Protons** ⊕	8	8
No. of Neutrons ○	12	12	**No. of Neutrons** ○	8	8
No. of Electrons ▬	12	10	**No. of Electrons** ▬	8	10
	Atom of Aluminum	Ion of Aluminum		Atom of Nitrogen	Ion of Nitrogen
Symbol	${}^{27}_{13}\mathrm{Al}$	${}^{27}_{13}\mathrm{Al}^{3+}$	**Symbol**	${}^{14}_{7}\mathrm{N}$	${}^{14}_{7}\mathrm{N}^{3-}$
Atomic Diagram			**Atomic Diagram**		
No. of Protons ⊕	13	13	**No. of Protons** ⊕	7	7
No. of Neutrons ○	14	14	**No. of Neutrons** ○	7	7
No. of Electrons ▬	13	10	**No. of Electrons** ▬	7	10

Read This!

Chemists refer to positively charged ions as **cations**. Chemists refer to negatively charged ions as **anions**.

7. Fill in the following table.

Symbol	$^{88}_{38}\text{Sr}^{2+}$	$^{32}_{16}\text{S}^{2-}$		
Atomic Number				35
Mass Number			70	
Number of protons			31	
Number of electrons			28	36
Number of neutrons				45
Cation or anion				

8. Could a +3 ion of aluminum be made by adding three protons to an aluminum atom? Explain.

9. One of your classmates is having trouble understanding ions. He explains the formation of a cation like this:

   "When you add an electron, you get a positive charge because adding is positive in math."

   a. As a group, explain in a grammatically correct sentence why this student is incorrect.

   b. Provide a better description of how math relates to electrons and ion formation.

Model 2 – Ion Charges for Selected Elements

	I	II					III	IV	V	VI	VII	VIII
1	H^+											
2	Li^+								N^{3-}	O^{2-}	F^{1-}	
3	Na^+	Mg^{2+}	transition elements				Al^{3+}		P^{3-}	S^{2-}	Cl^{1-}	
4	K^+	Ca^{2+}	Fe^{2+} Fe^{3+}	Ni^{2+} Ni^{3+}	Cu^+ Cu^{2+}	Zn^{2+}	Ga^{3+}				Br^{1-}	
5	Rb^+	Sr^{2+}			Ag^{1+}			Sn^{2+} Sn^{4+}			I^{1-}	
6		Ba^{2+}				$Hg_2^{\ 2+}$ Hg^{2+}		Pb^{2+} Pb^{4+}				

←CATIONS→←ANIONS→

10. Draw a stair-step line in Model 2 to separate the metals and nonmetals.

11. Consider the ions listed in Model 2.
    a. In general, do nonmetals form anions or cations?

    b. In general, do metals form anions or cations?

    c. Which nonmetal appears to be an exception to these guidelines?

Extension Questions

12. Name the family of elements that make 1– anions as shown in Model 2.

13. Name the family of elements that make 2+ cations as shown in Model 2.

14. For the main group elements (excluding the transition elements), is it necessary to memorize the type of ion each element makes or could you predict the ion charge using a periodic table? Explain.

15. In Model 2 there are several elements whose atoms make more than one type of ion. Where in the periodic table are these elements usually found?

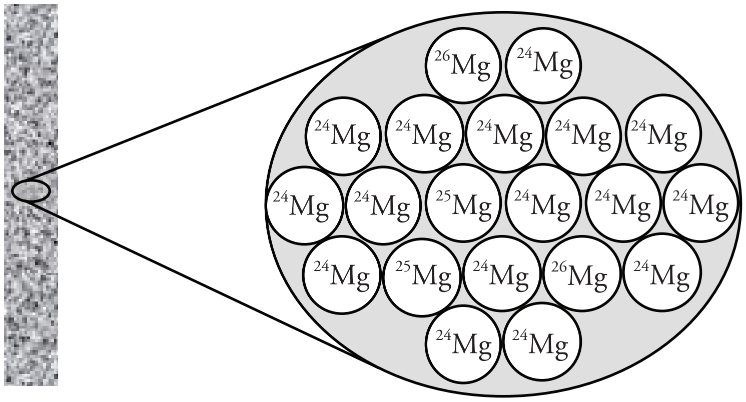
Average Atomic Mass

How are the masses on the periodic table determined?

Why?

Most elements have more than one naturally occurring isotope. As you learned previously, the atoms of those isotopes have the same atomic number (number of protons), making them belong to the same element, but they have different mass numbers (total number of protons and neutrons) giving them different atomic masses. So which mass is put on the periodic table for each element? Is it the most common isotope's mass? The heaviest mass? This activity will help answer that question.

Model 1 – A Strip of Magnesium Metal



^{26}Mg ^{24}Mg
^{24}Mg ^{24}Mg ^{24}Mg ^{24}Mg ^{24}Mg
^{24}Mg ^{24}Mg ^{25}Mg ^{24}Mg ^{24}Mg ^{24}Mg
^{24}Mg ^{25}Mg ^{24}Mg ^{26}Mg ^{24}Mg
^{24}Mg ^{24}Mg

1. Write in the atomic number for each Mg atom in Model 1.

2. What are the mass numbers of the naturally occurring isotopes of magnesium shown in Model 1?

3. Do all of the atoms of magnesium in Model 1 have the same atomic mass? Explain.

4. For the sample of 20 atoms of magnesium shown in Model 1, draw a table indicating the mass numbers of the three isotopes and the number of atoms of each isotope present.

5. Which isotope of magnesium is the most common in Model 1?

6. Based on Model 1 and the table you created in Question 4, for every 10 atoms of magnesium, approximately how many atoms of each isotope will be found?

Model 2 – Natural Abundance Information for Magnesium

Isotope	Natural Abundance on Earth (%)	Atomic Mass (amu)
^{24}Mg	78.99	23.9850
^{25}Mg	10.00	24.9858
^{26}Mg	11.01	25.9826

7. Consider the natural abundance information given in Model 2.
   a. Calculate the expected number of atoms of each isotope that will be found in a sample of 20 atoms of Mg. *Hint:* The number of atoms must be a whole number!

   b. Is Model 1 accurate in its representation of magnesium at the atomic level? Explain.

8. If you could pick up a single atom of magnesium and put it on a balance, the mass of that atom would most likely be ______ amu. Explain your reasoning.

9. Refer to a periodic table and find the box for magnesium.
   a. Write down the decimal number shown in that box.

   b. Does the decimal number shown on the periodic table for magnesium match any of the atomic masses listed in Model 2?

10. The periodic table does not show the atomic mass of every isotope for an element.
    a. Explain why this would be an impractical goal for the periodic table.

    b. Is it important to the average scientist to have information about a particular isotope of an element? Explain.

11. What would be a practical way of showing the mass of magnesium atoms on the periodic table given that most elements occur as a mixture of isotopes?

12. Propose a possible way to calculate the average atomic mass of 100 magnesium atoms. Your answer may include a mathematical equation, but it is not required.

Model 3 – Proposed Average Atomic Mass Calculations

Mary's Method

$$\frac{(78.99)(23.9850\text{ amu}) + (10.00)(24.9858\text{ amu}) + (11.01)(25.9826\text{ amu})}{100} = \underline{\qquad\qquad}$$

Jack's Method

$$(0.7899)(23.9850\text{ amu}) + (0.1000)(24.9858\text{ amu}) + (0.1101)(25.9826\text{ amu}) = \underline{\qquad\qquad}$$

Alan's Method

$$\frac{23.9850\text{ amu} + 24.9858\text{ amu} + 25.9826\text{ amu}}{3} = \underline{\qquad\qquad}$$

13. Complete the three proposed calculations for the average atomic mass of magnesium in Model 3.

14. Consider the calculations in Model 3.

    a. Which methods shown in Model 3 give an answer for average atomic mass that matches the mass of magnesium on the periodic table?

    b. Explain why the mathematical reasoning was incorrect for any method(s) in Model 3 that did not give the correct answer for average atomic mass (the one on the periodic table).

    c. For the methods in Model 3 that gave the correct answer for average atomic mass, show that they are mathematically equivalent methods.

15. Use one of the methods in Model 3 that gave the correct answer for average atomic mass to calculate the average atomic mass for oxygen. Isotope information is provided below. Show all of your work and check your answer against the mass listed on the periodic table.

Isotope	Natural Abundance on Earth (%)	Atomic Mass (amu)
^{16}O	99.76	15.9949
^{17}O	0.04	16.9991
^{18}O	0.20	17.9992

STOP

Read This!

Recall that all isotopes of an element have the same physical and chemical properties, with the exception of atomic mass (and for unstable isotopes, radioactivity). Therefore, the periodic table lists a weighted **average atomic mass** for each element. In order to calculate this quantity, the natural abundance and atomic mass of each isotope must be provided.

16. Consider the individual atomic masses for magnesium isotopes given in Model 2.

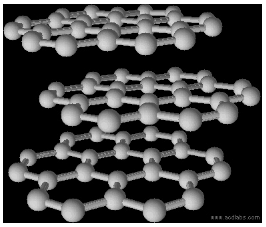
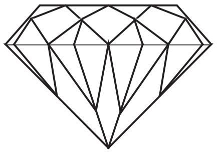
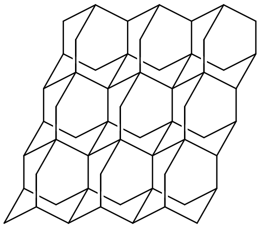
    a. Which isotope has an atomic mass closest to the average atomic mass listed on the periodic table?

    b. Give a mathematical reason for your answer to part *a*.

17. Boron has two naturally occurring isotopes: boron-10 and boron-11. Which isotope is more abundant on Earth? Use grammatically correct sentences to explain how your group determined the answer.

Extension Questions

Model 4 – Allotropes of Carbon

Natural Sample	Properties	Structure	Composition
Graphite	Black Soft Conductive		98.89% Carbon-12 1.11% Carbon-13
 Diamond	Colorless Very hard Insulator		98.89% Carbon-12 1.11% Carbon-13

18. Consider the information about carbon provided in Model 4.
    a. Are diamonds and graphite made from the same element?
    b. Can the existence of isotopes explain the difference in properties between diamond and graphite? Explain.
    c. Propose an explanation for the difference in properties between diamond and graphite.

19. O_2 and O_3 (ozone) are allotropes of oxygen. Buckminsterfullerene (C_{60}) is another allotrope of carbon. Based on these statements and the information in Model 4, propose a definition for **allotrope**.

20. Two common forms of phosphorus are red and white. Red phosphorus is fairly stable at room temperature in air, but white phosphorus can ignite easily when exposed to air. Is this difference in properties due to the existence of different isotopes of phosphorus or different allotropes? Explain.

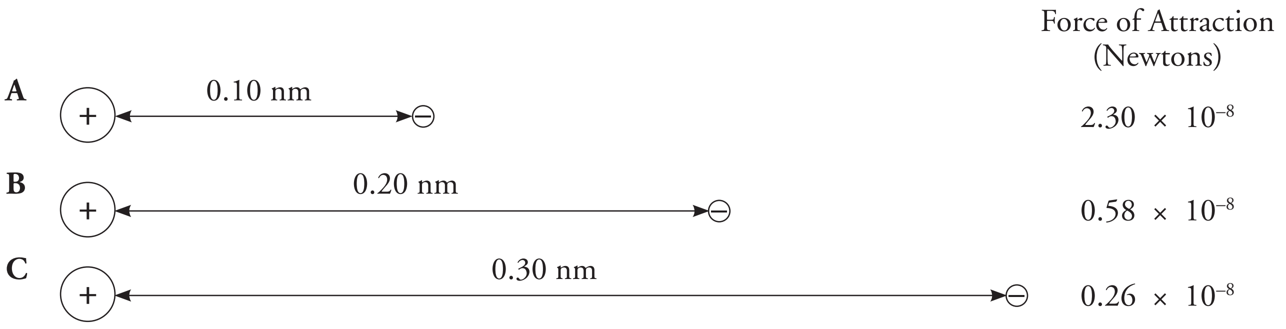
Coulombic Attraction

What variables will affect the force of attraction between charged particles?

Why?

Coulombic attraction is the attraction between oppositely charged particles. For example, the protons in the nucleus of an atom have attraction for the electrons surrounding the nucleus. This is because the protons are positive and the electrons are negative. The attractive force can be weak or strong. In this activity, you will explore the strength of attraction between protons and electrons in various atomic structures.

Model 1 – Distance and Attractive Force



1. What subatomic particles do these symbols represent in Model 1?

   ⊕ ⊖

2. Would you expect to observe attraction or repulsion between the subatomic particles in Model 1?

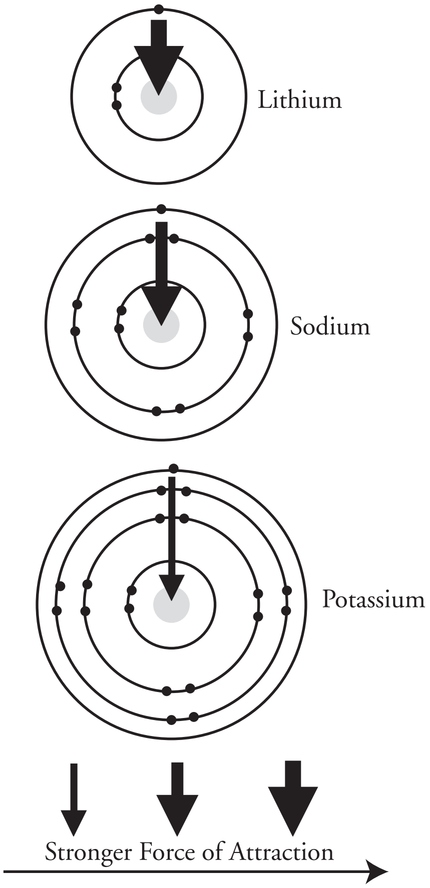
3. Consider the data in Model 1.
   a. What are the independent and dependent variables in the data?

   b. Write a complete sentence that describes the observed relationship between the independent and dependent variables in Model 1.

4. If the distance between a proton and electron is 0.50 nm, would you expect the force of attraction to be greater than or less than 0.26×10^{-8} N?

5. If two protons are 0.10 nm away from one electron, would you expect the force of attraction to be greater than or less than 2.30×10^{-8} N?

Model 2 – The Alkali Metals



6. Consider the diagrams in Model 2.
   a. What do the arrows represent?

   b. How does the thickness of the arrows relate to the property given in part *a*?

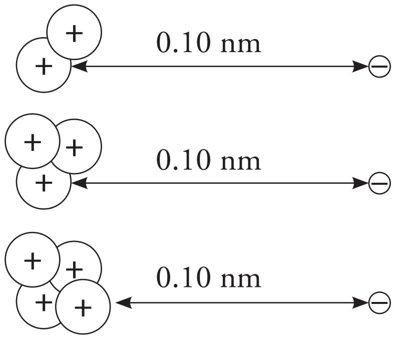
7. Using a periodic table, locate the elements whose atoms are diagrammed in Model 2. Are the elements in the same column or the same row?

8. Circle the outermost electron in each of the diagrams in Model 2.
   a. As you move from the smallest atom to the largest atom in Model 2, how does the distance between the outermost electron and the nucleus change?

   b. As you move from the smallest atom to the largest atom in Model 2, how does the attractive force between the outermost electron and the nucleus change?

   c. Are your answers to parts *a* and *b* consistent with the information in Model 1?

Model 3 – Number of Protons and Attractive Force



	Force of Attraction (Newtons)
A	2.30×10^{-8}
D	4.60×10^{-8}
E	6.90×10^{-8}
F	9.20×10^{-8}

9. Consider the data in Model 3.

   a. What are the independent and dependent variables in the data?

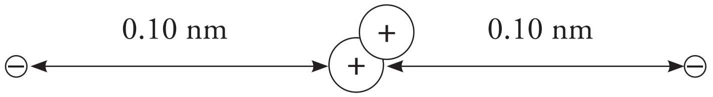
   b. Write a complete sentence that describes the relationship between the independent and dependent variables in Model 3.

10. What would be the attractive force on a single electron if five protons were in the nucleus of an atom? Show mathematical work to support your answer.

11. Imagine that a second electron were placed to the left of a nucleus containing two protons (Model 3, set D). Predict the force of attraction on both the original electron and the second electron. Explain your prediction with a complete sentence.

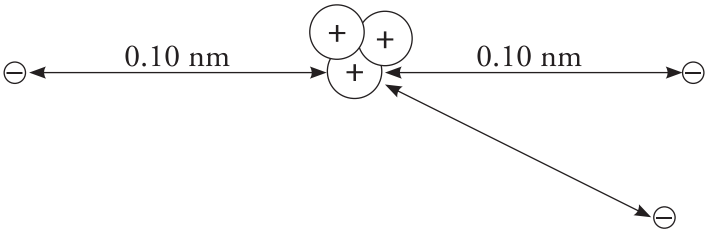
Read This!

The attractive and repulsive forces in an atom are rather complex. An electron is attracted to the protons in the nucleus, but it is also repelled by the other electrons in the atom. It is important to note however that the attractive force of the nucleus is NOT divided up among the electrons in the atom. Each electron gets approximately the full attractive force of the nucleus (minus the repulsive effects of other electrons). Compare the diagram below to set D in Model 3. Notice the similarity in attractive force.

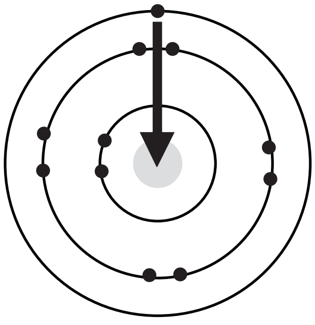


approx. 4.60 × 10^{-8}
(on each electron)

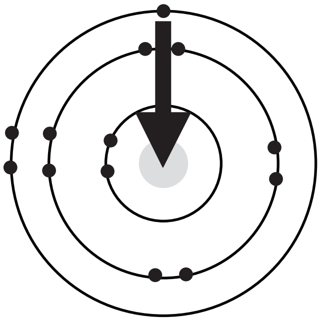
12. What is the approximate attractive force on each electron below?



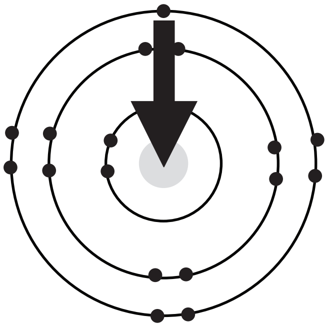
Model 4 – Period 3 Elements



Sodium



Aluminum



Chlorine

13. Using the periodic table, locate the elements whose atoms are diagrammed in Model 4. Are the elements in the same column or the same row?

14. Circle the outermost electron(s) in each of the atoms in Model 4.

15. Which of the three atoms diagrammed in Model 4 has the strongest attraction for its outermost electron(s)?

16. Consider the information in Model 4.

    a. As you move from the smallest atom to the largest atom, does the distance between the outermost electron(s) and the nucleus change significantly?

    b. Can the differences in the attractive force shown by the arrows be explained by a change in the distance between the electron(s) and the nucleus?

    c. On the diagrams in Model 4, write the number of protons located in the nucleus of each atom.

    d. Can the differences in attractive forces shown by the arrows in Model 4 be explained by a change in the number of protons in the nucleus? If yes, explain the relationship in Model 4.

17. For each set of elements below, circle the element whose atoms will have a stronger attractive force between their outermost electron(s) and the nucleus.

    a. Ba and Ca   *b.* Cr and Cu   *c.* Ar and Xe

Extension Questions

18. Consider the atom diagrams in Model 2.

    a. On each diagram write the number of protons in the nucleus of the atom.

    b. When comparing elements in the same column of the periodic table, which factor—distance to the nucleus or number of protons in the nucleus—seems to be the dominant factor for determining the attractive force between the outermost electron(s) and the nucleus? Explain.

19. Consider the data presented in Models 1 and 3.

    a. Describe the mathematical relationship between the distance (d) and the attractive force (F) between protons and electrons.

    b. Describe the mathematical relationship between the number of protons in the nucleus (Z) and the attractive force (F) between the nucleus and electrons.

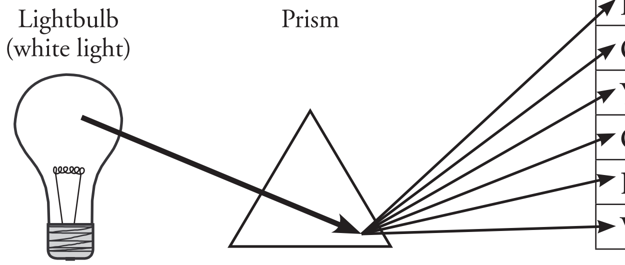
Electron Energy and Light

How does light reveal the behavior of electrons in an atom?

Why?

From fireworks to stars, the color of light is useful in finding out what's in matter. The emission of light by hydrogen and other atoms has played a key role in understanding the electronic structure of atoms. Trace materials, such as evidence from a crime scene, lead in paint or mercury in drinking water, can be identified by heating or burning the materials and examining the color(s) of light given off in the form of bright-line spectra.

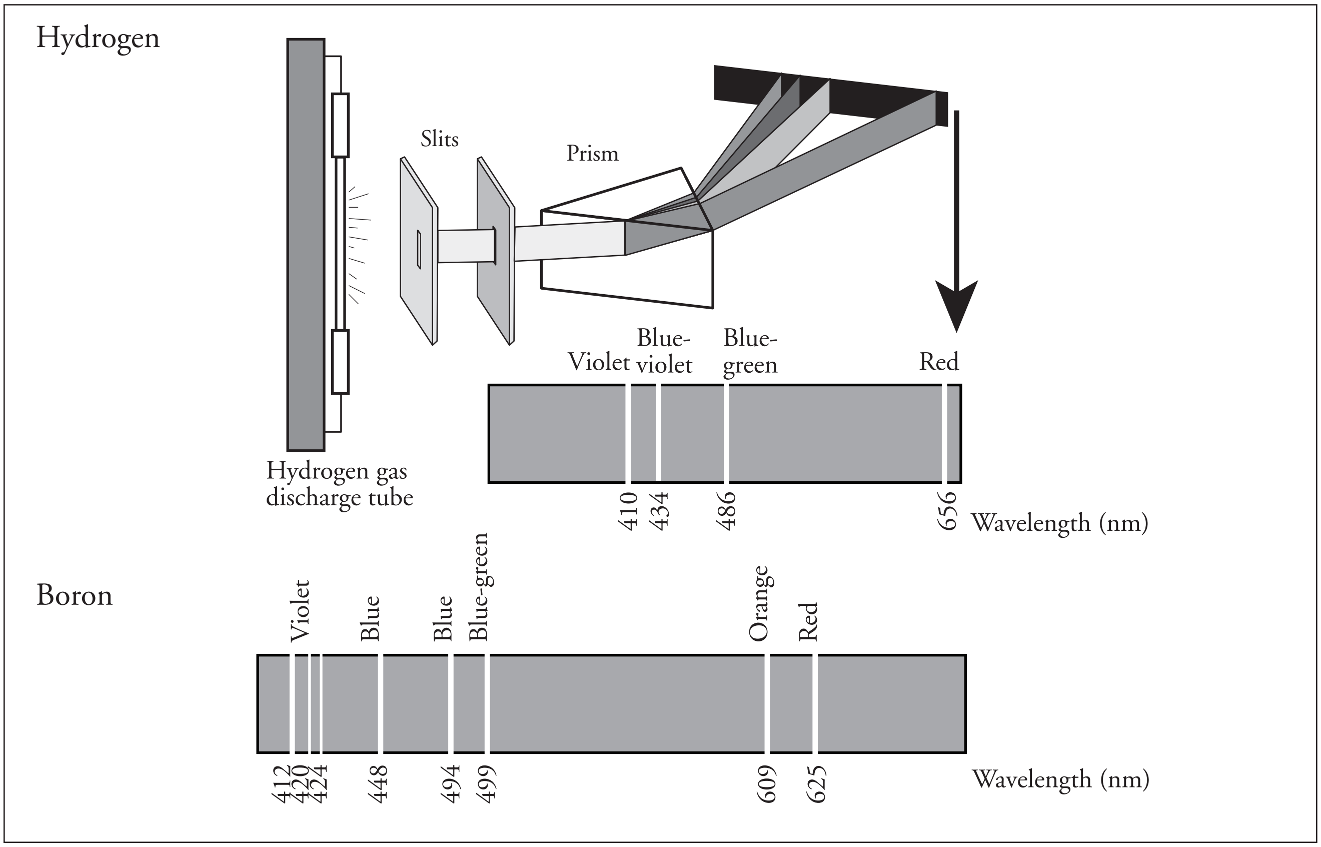
Model 1 – White Light



Color	Photon Energy ($\times 10^{-21}$) (J)	Wavelength Range (nm)	Speed (m/s)
Reds	269–318	625–740	3.00×10^8
Oranges	318–337	590–625	3.00×10^8
Yellows	337–352	565–590	3.00×10^8
Greens	352–382	520–565	3.00×10^8
Blues	382–452	440–520	3.00×10^8
Violets	452–523	380–440	3.00×10^8

1. Trace the arrows in Model 1 and shade in the table with colored pencils where appropriate.
2. What happens to white light when it passes through a prism?
3. Why are the color labels in the table in Model 1 plural (*i.e.,* "Reds" rather than "Red")?
4. Do all colors of light travel at the same speed?
5. Do all colors of light have the same energy? If no, which colors have the highest energy and the least energy, respectively?
6. Consider the light illustrated in Model 1.
   - *a.* Which color corresponds to the longest wavelengths?
   - *b.* Which color corresponds to the shortest wavelengths?
   - *c.* Write a sentence that describes the relationship between wavelength and energy of light.

Model 2 – Emission Spectra for Hydrogen and Boron Atoms



7. Use colored pencils to color the hydrogen and boron spectral lines within their respective spectra in Model 2.
8. List the spectral lines for hydrogen gas by color and corresponding wavelength.
9. The spectral lines for boron were produced using the same method as hydrogen. List three of the colors and corresponding wavelengths for boron's spectral lines as its light passes through a prism.
10. Consider the hydrogen spectrum in Model 2.
    - *a.* Which color of light corresponds to the shortest wavelength?
    - *b.* Which color of light corresponds to the longest wavelength?

11. Consider the hydrogen spectrum in Model 2.
    a. Which color of light has the most energy?

    b. Which color of light has the least energy?

12. Does a gas discharge tube filled with boron emit the same wavelengths of light as a tube filled with hydrogen? Use evidence from Model 2 to support your answer.

13. "The spectral lines for atoms are like fingerprints for humans." How do the spectral lines for hydrogen and boron support this statement?

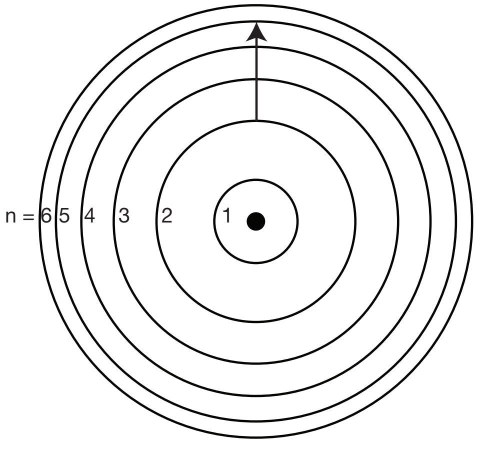
Circle the appropriate word to complete each statement in Questions 14–17.

14. Electrons and protons (attract/repel) each other.
15. As an electron gets closer to the nucleus the (attraction/repulsion) to the nucleus gets (stronger/weaker).
16. For an electron to move from an energy level close to the nucleus to an energy level far from the nucleus it would need to (gain/lose) energy.
17. For an electron to move from an energy level far from the nucleus to an energy level close to the nucleus it would need to (gain/lose) energy.

Read This!

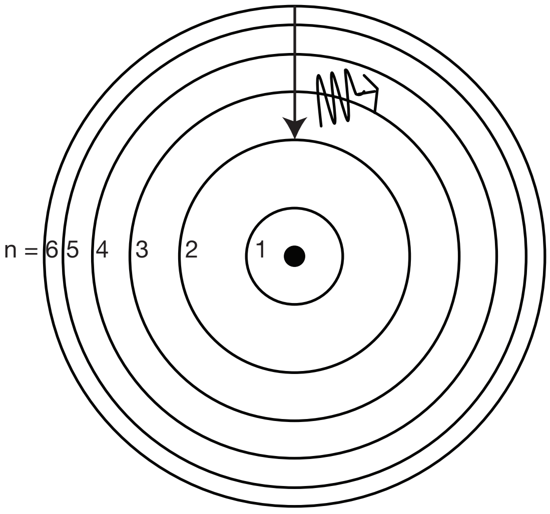
Niels Bohr modified Rutherford's Nuclear Atom model to explain how light interacted with the electrons in an atom to produce spectral lines. His model included electrons orbiting the nucleus at specific energy levels. Electrons absorb energy from various sources (electricity) when they move from lower energy levels (ground state) to higher energy levels (excited states). Energy is released as electrons return to their lower energy levels.

18. Is energy absorbed or released for the electron transition shown in the diagram to the right? Explain.

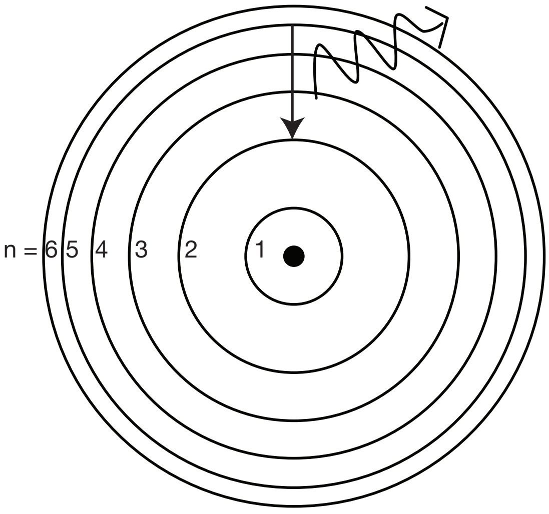


Model 3 – Bohr Model of a Hydrogen Atom

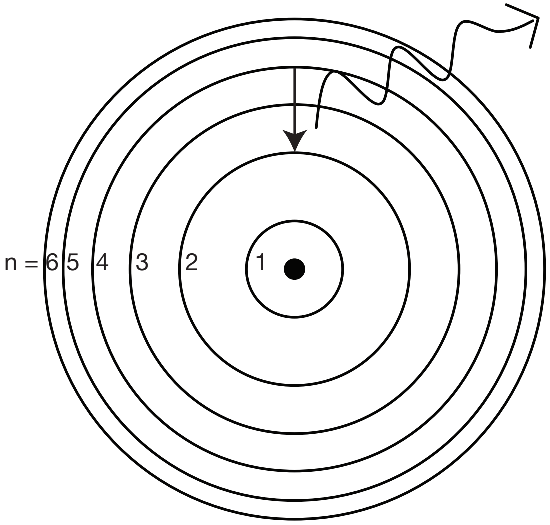
A. ____________________



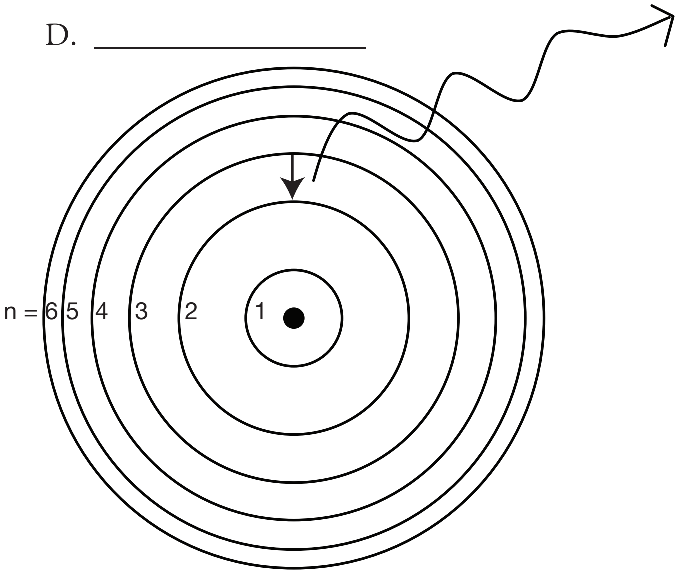
B. ____________________



C. ____________________



D. ____________________



19. Identify the drawing in Model 3 that depicts a hydrogen atom with an electron moving from energy level 5 to energy level 2. Refer to Models 1 and 2 for the following questions.
    a. Label the picture with “n=5 to n=2” and list the corresponding color of light emitted.
    b. This electron transition (absorbs/releases) energy.
    c. This electron moves from a (lower/higher) energy state to a (lower/higher) energy state.
    d. Is light absorbed or released in the electron transition?

20. Label the remaining drawings in Model 3 with the electron transitions that are occurring (n=? to n=?), the wavelengths, and the corresponding colors as given in example A in Model 3. See Model 2 in order to identify the color of spectral lines produced in each of the hydrogen atom electron transitions shown in Model 3. Use colored pencils to trace the light wave in each of the four pictures with the appropriate color.

21. Consider the electron transitions in Model 3.

    a. Which of the electron transitions involves the most energy?

    b. Explain why this transition involves the most energy based on your understanding of the attractive forces between the electrons and protons in the atom.

22. Explain why a single atom of hydrogen cannot produce all four hydrogen spectral lines simultaneously.

23. If Question 22 is true, how can we see all four colors from a hydrogen gas discharge tube simultaneously?

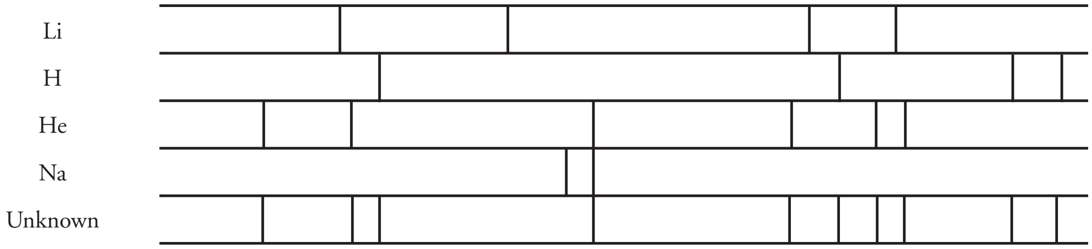
Extension Questions

24. The hydrogen spectral lines in Model 2 are only the wavelengths of light that are in the visible range and therefore “seen” by the naked eye. However, many other wavelengths can be detected with special equipment.

    a. Propose a hydrogen electron transition that involves light with a wavelength in the ultraviolet (UV) range (10–400 nm).

    b. Propose a hydrogen electron transition that involves light with a wavelength in the infrared (IR) range (1000–106 nm).

25. Below are diagrams for the bright line spectra of four elements and the spectrum of a mixture of unknown gases.



    a. Which element(s) are not present in the Unknown?

    b. Which element(s) are in the Unknown?

26. Model 2 shows the emission spectra for hydrogen and boron. Scientists can also record the absorption spectra for elements. Propose how this might be done, and what the absorption spectra of hydrogen and boron would look like.

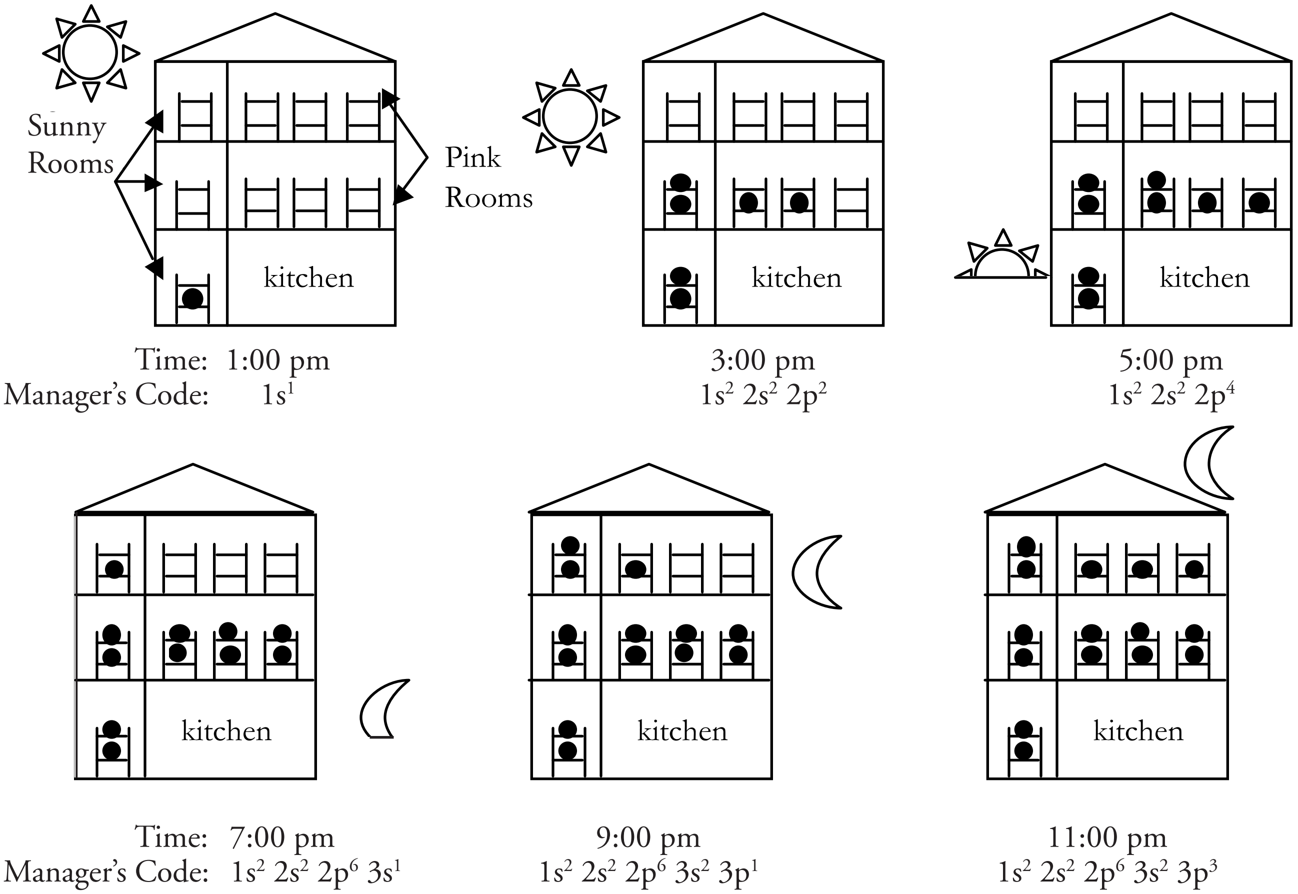
Electron Configurations

What is the electron structure in an atom?

Why?

The electron structure of an atom is very important. Scientists use the electronic structure of atoms to predict bonding in molecules, the charge(s) an atom might have, and the physical properties of elements. In order for scientists to describe the electron structure in an atom, they give the electrons "addresses." Just like your address might include your house number, street, city, and state, an electron's "address" has multiple parts. In this activity, you will learn how the electrons fill up the available spaces in an atom and how their "addresses" or configurations are assigned.

Model 1 – The Boarding House



Time: 1:00 pm
Manager's Code: $1s^1$

3:00 pm
$1s^2\ 2s^2\ 2p^2$

5:00 pm
$1s^2\ 2s^2\ 2p^4$

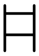
Time: 7:00 pm
Manager's Code: $1s^2\ 2s^2\ 2p^6\ 3s^1$

9:00 pm
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$

11:00 pm
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$

1. Examine the boarding house diagrams in Model 1. Match each symbol below with its most likely meaning.

_____*a.* ● I. Bunk bed for boarders

_____*b.*  II. Manager's code for the number of boarders in the house and their room assignments.

_____*c.* $1s^2\ 2s^2\ 2p^6\ 3s^1$ III. Boarder

2. Refer to Model 1.

   a. How many boarders were in the boarding house at 5:00 pm?

   b. Describe how you determined your answer to part *a*.

3. Examine each diagram in Model 1 and the corresponding manager's code. Using the following manager's code:

$$1\,s^{2}\quad 2\,s^{2}\quad 2\,p^{4}$$

   a. Underline the floor numbers.

   b. Circle the types of rooms.

   c. Draw a box around the numbers of boarders.

4. The manager of the boarding house has some very strict rules on how beds will be rented out for the night. Examine the diagrams in Model 1 and the statements below to determine the phrase that best describes the manager's set of rules. Circle the correct answer.

   a. The boarding house will rent out beds on the ________ floor first.

   1st 2nd 3rd

   b. Boarders are only allowed to double up in a bunk in a room when ________________________.

   there is an even number of boarders in the room all bottom bunks are occupied

   c. The next floor of rooms will be opened for boarders only when ________________________ on the floor below are occupied.

   half of the bunks at least one of the rooms all of the bunks

   d. The pink room on a floor will be opened for boarders only when ________________________.

   all of the lower bunks in the sunny room on that floor are occupied

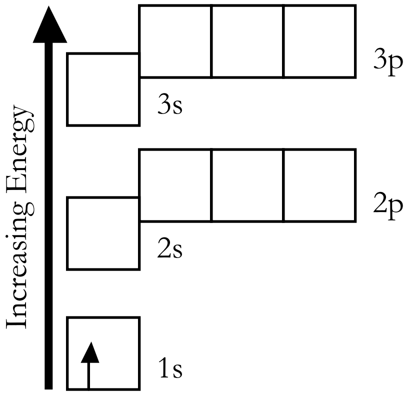
   all of the bunks in the sunny room on that floor are occupied

   the sunny room on that floor is open

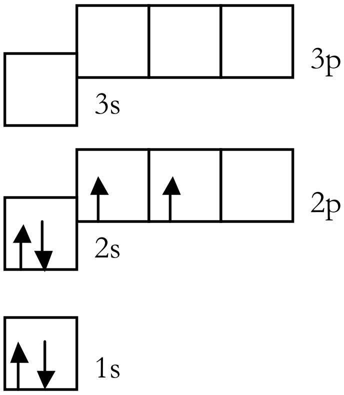
5. Provide (a) the manager's code and (b) a boarding house diagram showing 12 boarders present.

   a. *b.*

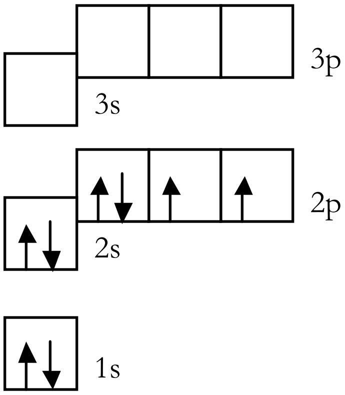
Model 2 – Ground State Orbital Diagrams and Electron Configurations



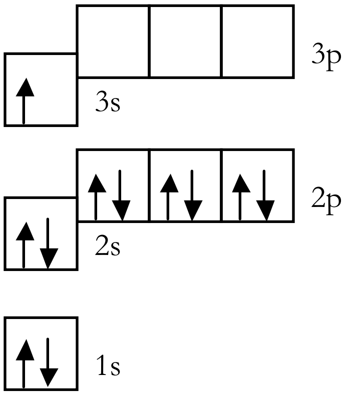
Hydrogen
$1s^1$



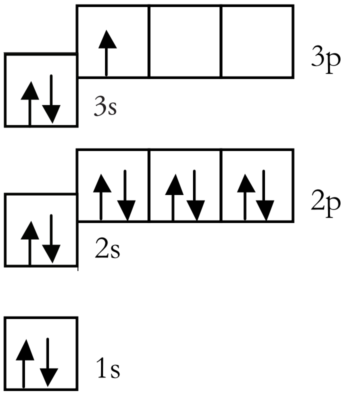
Carbon
$1s^2\ 2s^2\ 2p^2$



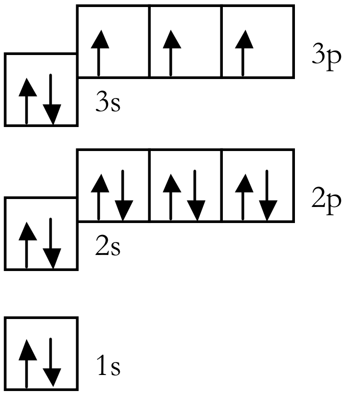
Oxygen
$1s^2\ 2s^2\ 2p^4$



Sodium
$1s^2\ 2s^2\ 2p^6\ 3s^1$



Aluminum
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$



Phosphorus
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$

6. Examine the orbital diagrams and electron configurations in Model 2. Match each symbol below with its meaning.

____*a.* ☐ I. Single electron
____*b.* ↑ II. Pair of electrons with opposite spins
____*c.* ↑↓ III. Atomic orbital (region of space where an electron is likely to be found)
____*d.* ☐☐☐ IV. Sublevel (set of orbitals having equivalent energy)
____*e.* $1s^2\ 2s^2\ 2p^4$ V. Electron configuration

7. Consider the orbital diagram for oxygen in Model 2.

   a. How many electrons are present in the orbital diagram?

   b. Based on its position in the periodic table, explain how you know that your answer to part *a* is the *correct* number of electrons for oxygen.

8. Examine the orbital diagrams and electron configurations in Model 2. Using the following electron configuration:

$$1s^2 \quad 2s^2 \quad 2p^4$$

   a. Underline the energy levels.

   b. Circle the sublevels.

   c. Draw a box around the numbers of electrons.

9. The 2s and 2p sublevels are very close in energy, as are the 3s and 3p sublevels. Explain how the orbital diagram for sodium confirms that the 3s sublevel is lower in energy than the 3p sublevel.

10. The lowest potential energy arrangement of electrons in an atom is called the **ground state**. Ground state electron configurations can be predicted by a strict set of rules known as the **Aufbau principle** ("aufbau"means filling up). Examine the diagrams in Model 2 and the statements below to determine the phrase that best describes each rule. Circle the correct answer.

    a. Based on where a single electron is placed, the lowest potential energy electron in an atom is found in the ________ sublevel.

    1s 2s 3s

    b. Electrons will occupy a p-orbital only after ____________ .

    the previous s-orbital is half full

    the previous s-orbital is completely full

    the previous s-orbital is empty

    c. Electrons can begin to occupy energy levels with the next highest integer designation (e.g., 2 vs. 1, 3 vs. 2) only after __________________ on the energy level below it are occupied.

    half of the orbitals at least one of the orbitals all of the orbitals

11. The **Pauli exclusion principle** describes the restriction on the placement of electrons into the same orbital. The Pauli exclusion principle can be expressed as: "If two electrons occupy the same orbital, they must have ____________________." Circle the correct answer.

    the same spin　　　　　　　　opposite spins

12. **Hund's rule** describes how electrons are distributed among orbitals of the same sublevel when there is more than one way to distribute them. Hund's rule consists of two important ideas. Based on Model 2, circle the correct answer to each statement.

    a. Electrons will pair up in an orbital only when ____________________

    there is an even number of electrons in the sublevel

    all orbitals in the same sublevel have one electron

    b. When single electrons occupy different orbitals of the same sublevel, ____________________.

    they all have the same spin

    they all have different spins

    their spins are random

13. For each of the symbols below from Model 2, provide the name or description of the analogous component that was used in the boarding house model (Model 1).

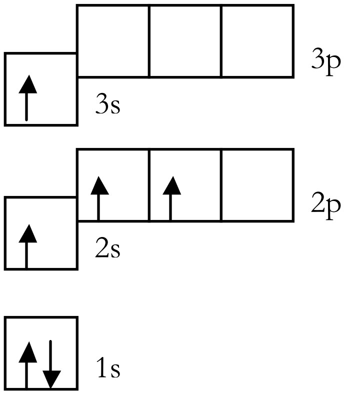
    a.

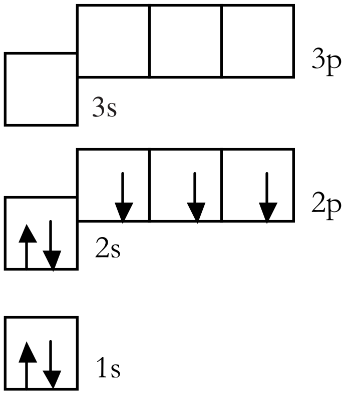
☐	
☐☐☐	
↑	
↑↓	
$1s^2\ 2s^2\ 2p^4$	

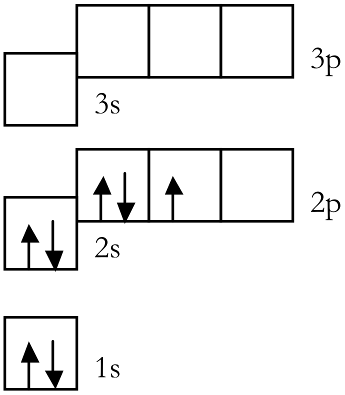
b. What characteristic of electrons is *not* well represented by the boarding house model?

c. How could the boarding house model be modified to better represent the relative energies of s and p sublevels?

14. Below are three answers generated by students in response to the prompt: "Provide an orbital energy level diagram for the ground state of a nitrogen atom." In each case, indicate whether the answer is right or wrong, and if it is wrong, explain the error.



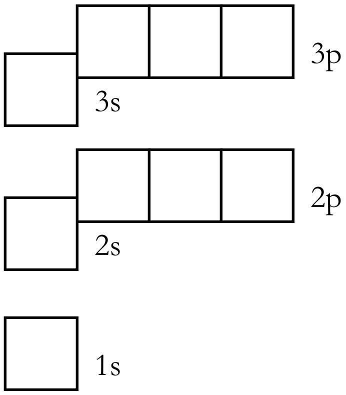




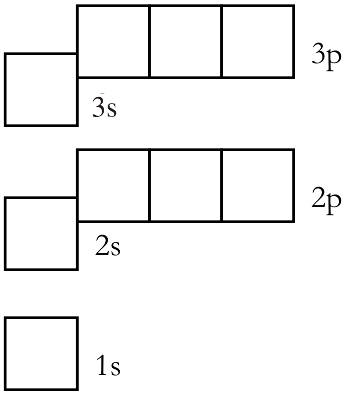
a.	b.	c.

15. Complete the ground state orbital energy level diagrams and write the corresponding electron configurations for:

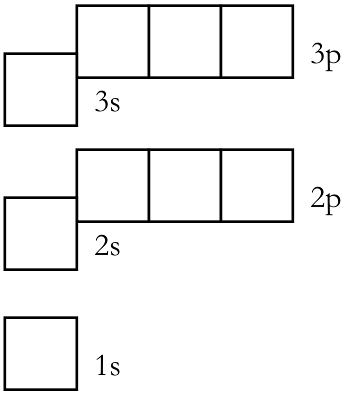
Sulfur



Silicon



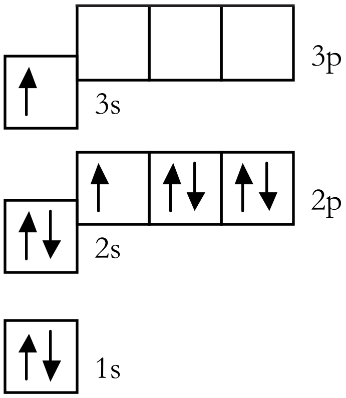
Neon



Sulfur	Silicon	Neon

Extension Questions

Model 3 – Orbital Diagram for an Atom of Element X



16. Consider the orbital diagram in Model 3.
    a. How many electrons are there in one atom of element X?

    b. Identify element X and provide its ground state electron configuration. Assume the atom is neutral.

    c. Is the arrangement of electrons in the orbital diagram in Model 3 higher in total potential energy or lower in total potential energy than the ground state electron configuration of element X? Explain your reasoning.

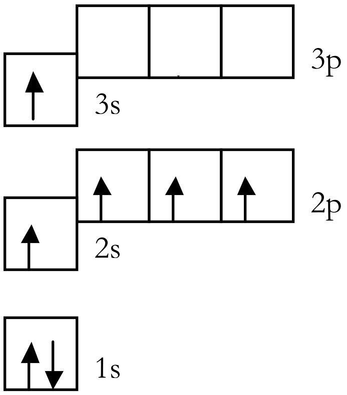
Read This!

An **excited state electron configuration** is *any* electron configuration for an atom that contains the correct total number of electrons but has a higher total electron potential energy than the ground state electron configuration.

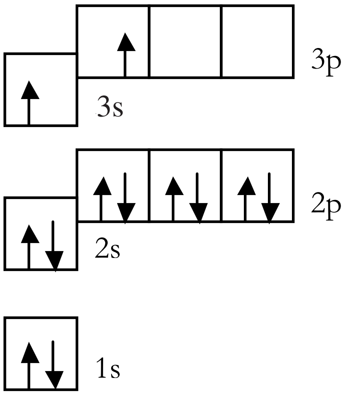
17. Write an electron configuration for element X that shows the atom in a different excited state than the one illustrated in Model 3.

18. Each orbital diagram shown below describes an excited state of an atom of a *different* element. Use the orbital diagrams to complete the table.

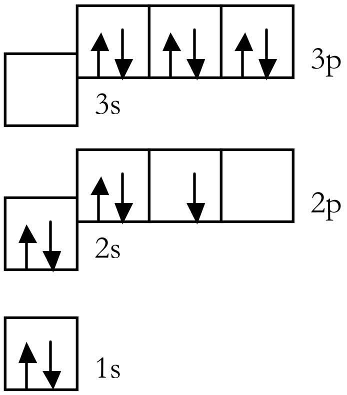
A



B



C



	A	**B**	**C**
Excited state electron configuration			
Identify the element			
Ground state electron configuration			

19. Complete the table for each of the excited state electron configurations given.

Excited state electron configuration	**Element name**	**Ground state electron configuration**	**Orbital diagram for ground state**
$1s^2\ 2s^1\ 2p^2$			
$1s^2\ 2s^2\ 2p^2\ 3s^2\ 3p^1$			

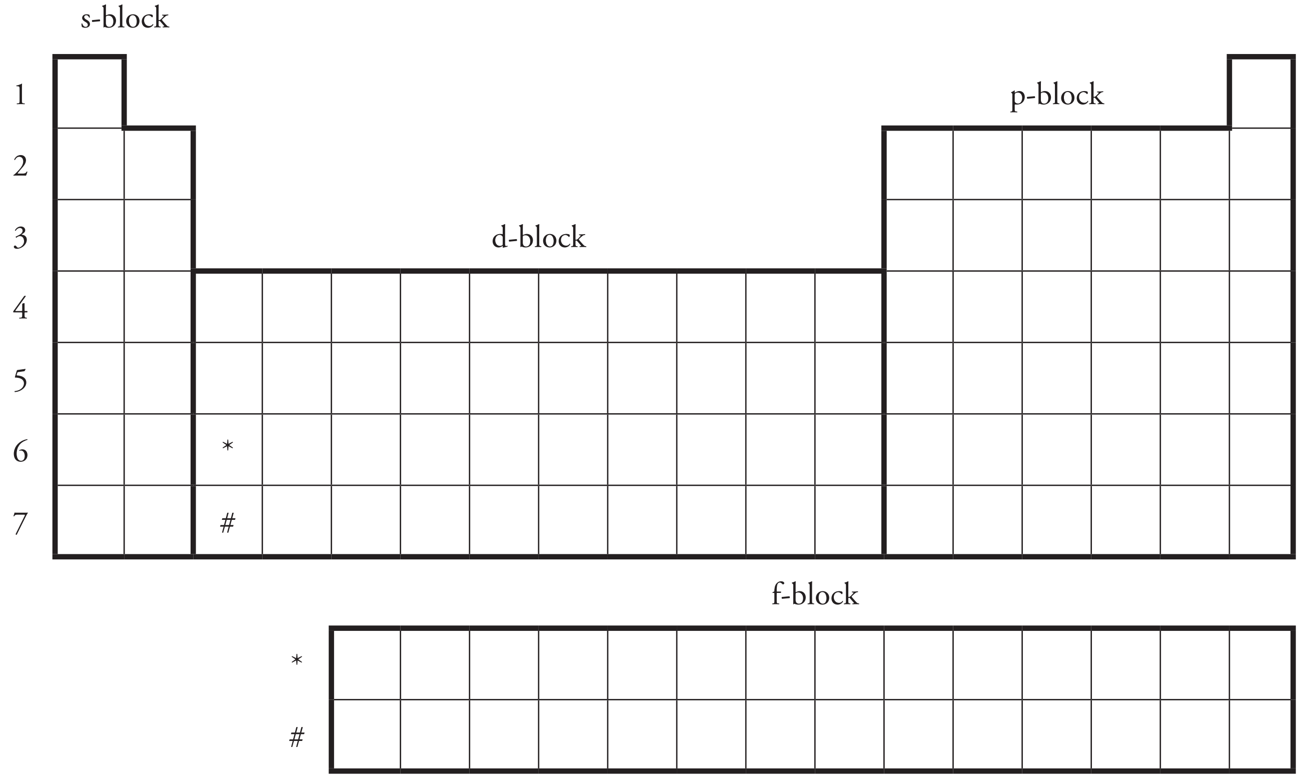
Cracking the Periodic Table Code

Why aren't the elements listed in alphabetical order?

Why?

As charts go, the periodic table is a bit odd. It's not square. Large portions of the table appear to be missing at the top. It's not organized alphabetically so elements can be found easily. But to a chemist, the periodic table is a very powerful tool. The periodic table is organized by properties, both chemical and physical. Those properties relate to the electronic structure of the atoms of each element. In today's activity, you are going to study how the ground state electron configurations and structure of atoms are related to the shape and organization of the periodic table.

Model 1 – Blank Periodic Table



1. Obtain a card with electron configurations for your group as assigned by your teacher.
   a. Record your team number______ and team name ________________________________.
   b. For each element on your card, write the last orbital notation appearing at the end of the configuration (the underlined portion).

2. What is similar about the last orbital notation appearing at the end of the configuration for each element in your set?

3. Locate where your set of elements should be in Model 1.
   a. Write the last orbital notation in the electron configuration for each element in your set in its respective box.

   b. What is the relationship between your answer in Question 2 and the “block” of the table where your set of elements is located?

4. What is the relationship between the last orbital notation in your set of ground state electron configurations and the row numbers on the left-hand side of the periodic table in Model 1?

STOP

Read This!

Go on a search—send a representative of your group to other tables to find out what they have discovered in Questions 1–4. Add the last orbital notation for their groups of elements to Model 1. Talk to at least one team from each of the “blocks” (*i.e.,* you want to look at a set of elements in the s-block, d-block, p-block, and f-block). It is NOT the goal of this activity to fill in the entire periodic table. You just need a few data points in each section to answer the questions that follow.

5. Count the number of columns in each of the four “blocks” of the table in Model 1. What is the relationship between the “block” size and the number of electrons that will fit in the corresponding atomic sublevel?

6. What is the relationship between where an element is located within a “block” of the table in Model 1 and the superscripted (raised, like an exponent) value appearing at the end of the electron configuration for that element?

STOP

7. Obtain the Electron Energy Levels handout from your teacher. Put the Electron Energy Levels handout next to Model 1. Start at the bottom of the Electron Energy Levels handout with the 1s energy sublevel and locate the section of the periodic table corresponding to that sublevel. Why are there only two elements in the first row of the periodic table?

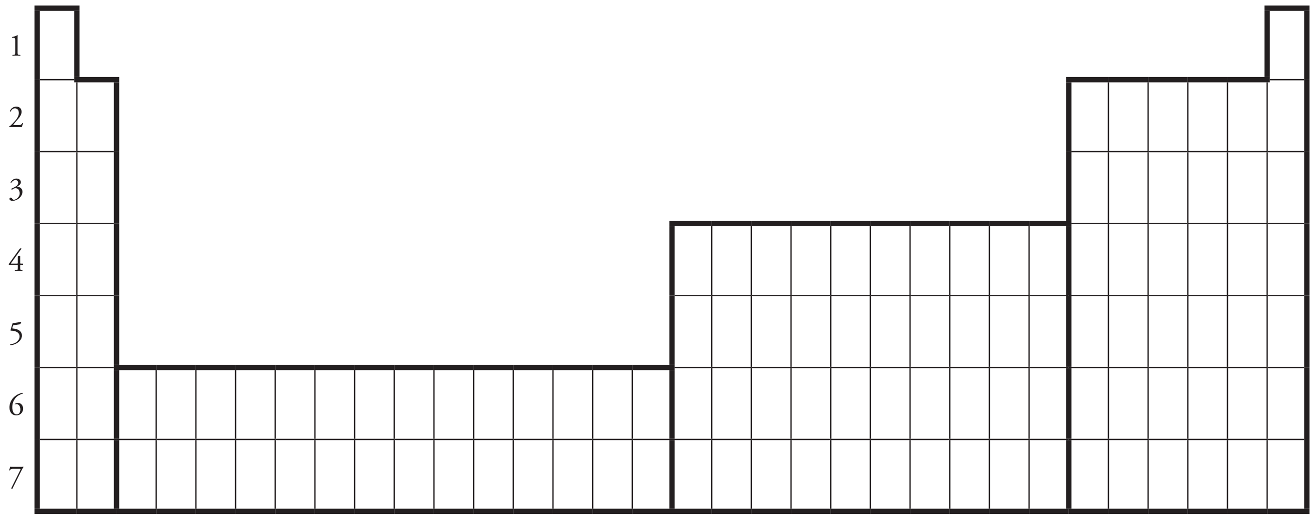
8. Work your way up the Electron Energy Levels diagram, locating as many sublevel sections as you can on Model 1.
   a. Why does the second row of the periodic table not have a "d-block" section?

   b. The third energy level in an atom contains a d sublevel. Why then does the "d-block" start in the fourth row of the periodic table?

9. For the elements of the "d-block" how is the row number related to the principal energy level for the last orbital notation of their electron configurations?

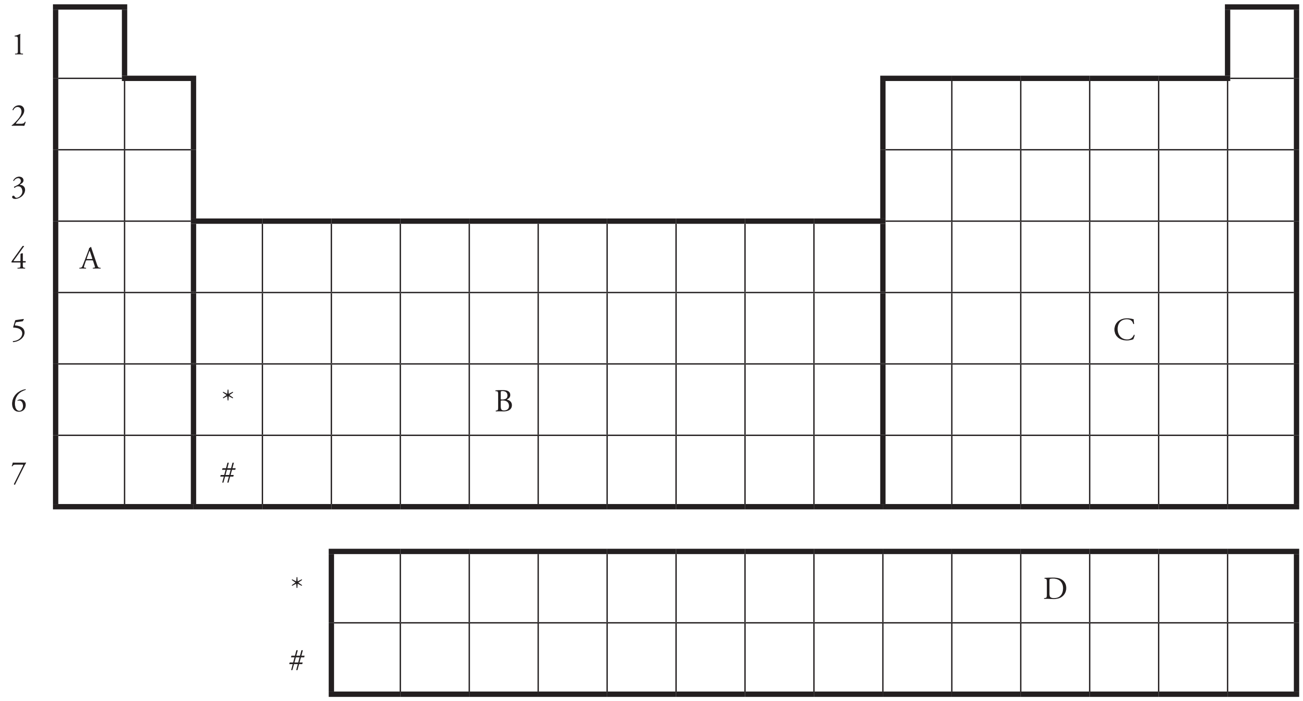
10. Obtain from your teacher the Periodic Table handout and a pair of scissors. Cut out the sections as instructed and reassemble the periodic table sequentially by atomic number.

Model 2 – Periodic Table (Long Form)



11. Use your group's reconstructed periodic table to label the sections of Model 2.
12. Compare the periodic table of Model 1 with the periodic table of Model 2. What section of the table was moved?
13. What do the * and # symbols in Model 1 indicate?
14. The form of the periodic table seen in Model 2 is called the "long form" of the table. You do not often see this form in books or posters. What are the disadvantages of this form?
15. Explain why the "f-block" does not appear until the 6th row, and why it fits in-between the "s" and "d" blocks. (*Hint:* Refer to the Electron Energy Levels handout.)
16. For the elements in the "f-block," how is the row number related to the principal energy level for the last orbital notation of their electron configurations?"

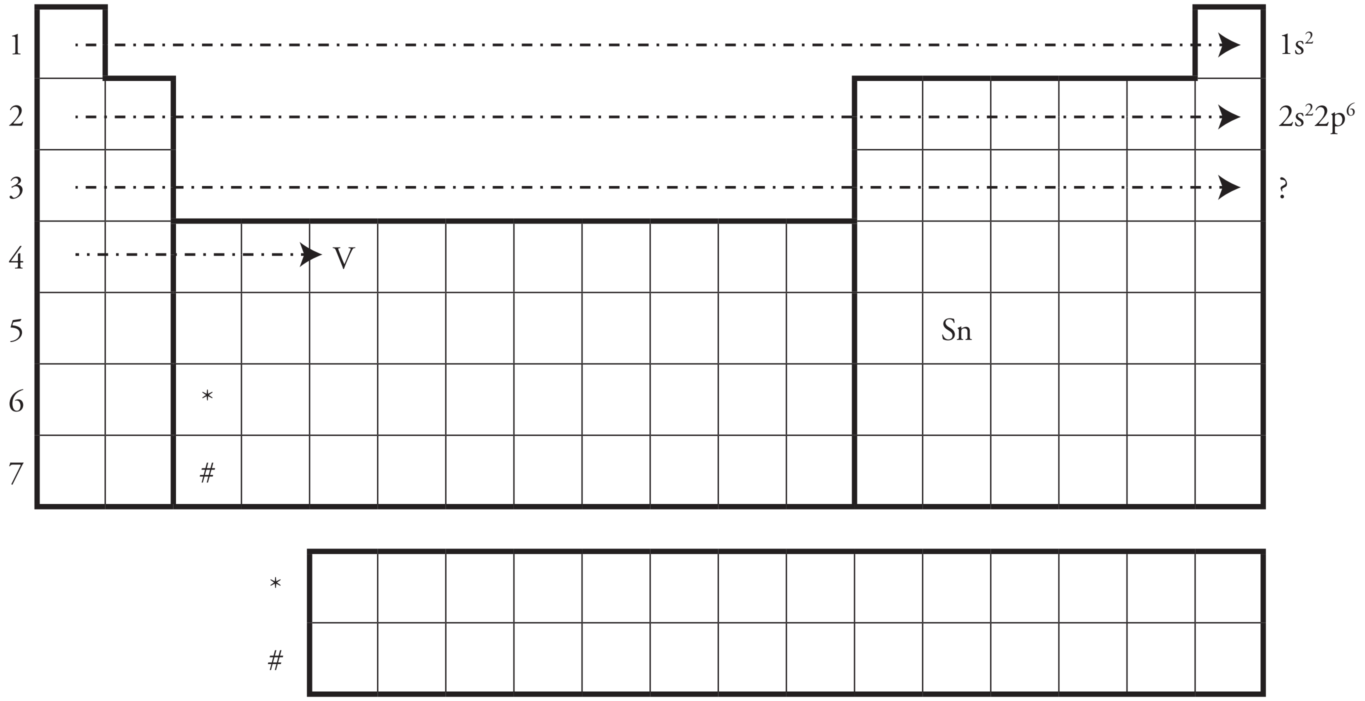
17. Write the last orbital notation in the electron configurations for the elements located at A, B, C, and D in the table below. You should not have to "count" electrons to do this if you understand the structure of the periodic table.



A ____________________ B ____________________

C ____________________ D ____________________

Model 3 – Use of the Periodic Table for Electron Energy Levels



18. Now that you understand how the structure of the periodic table relates to electron sublevels, you can use it as a "cheat sheet" for the order of filling of electrons in the sublevels of the atom. The following steps will help you write the ground state electron configuration for vanadium, V.

    a. Use your finger to trace a line across the top row of the periodic table in Model 3. Explain why the two boxes in that row represent $1s^2$.

    b. Trace a line across row two of the periodic table. Explain why this row represents $2s^22p^6$.

    c. Trace a line across row three of the periodic table. Record the sublevels and number of electrons that will be filled by the time you reach the end of this line.

    d. Trace a line across row four ending at vanadium, V, and record the sublevels and number of electrons that are filled to reach that point.

    e. Combine the steps above to write the full ground state electron configuration for vanadium (V).

19. Using only a periodic table, write the full ground state electron configuration for an atom of tin (Sn).

20. The electron configuration for an unknown element is:

    $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^66s^24f^{14}5d^{10}6p^67s^25f^{14}6d^4$

    a. Identify the element and write its symbol in its proper location of Model 3.

    b. Describe two different methods that could be used to identify this element.

Extension Questions

Model 4 – Predicted versus True Configuration

	Predicted Configuration	**True Configuration** (Supported by scientific evidence)
Cr	$1s^22s^22p^63s^23p^64s^23d^4$	$1s^22s^22p^63s^23p^64s^13d^5$
Cu	$1s^22s^22p^63s^23p^64s^23d^9$	$1s^22s^22p^63s^23p^64s^13d^{10}$
Ce	$1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^66s^24f^2$	$1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^66s^24f^15d^1$

21. For each of the elements in Model 4, circle the portion of the true electron configuration that differs from the predicted configuration.

22. Construct a possible explanation for why the true configurations would be a lower potential energy state for the elements in Model 4. *Hint:* What types of atomic interactions cause a lower potential energy or higher potential energy? How far apart in energy are electrons in the higher energy levels?

Periodic Trends

Can the properties of an element be predicted using a periodic table?

Why?

The periodic table is often considered to be the "best friend" of chemists and chemistry students alike. It includes information about atomic masses and element symbols, but it can also be used to make predictions about atomic size, electronegativity, ionization energies, bonding, solubility, and reactivity. In this activity you will look at a few periodic trends that can help you make those predictions. Like most trends, they are not perfect, but useful just the same.

---

1. Consider the data in Model 1 on the following page.
   a. Each element has three numbers listed under it. Which value represents the atomic radius?
   b. What are the units for the atomic radius?
   c. Write a complete sentence to convey your understanding of atomic radius. *Note:* You may not use the word "radius" in your definition.

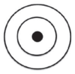
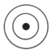
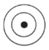
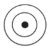
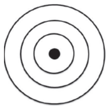
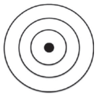
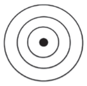
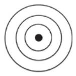
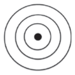
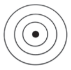
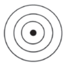
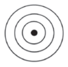
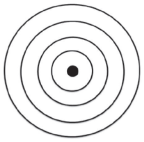
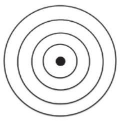
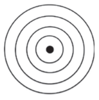
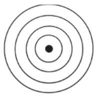
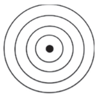
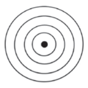
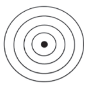
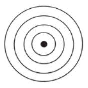
2. In general, what is the trend in atomic radius as you go down a group in Model 1? Support your answer, using examples from three groups.

3. Using your knowledge of Coulombic attraction and the structure of the atom, explain the trend in atomic radius that you identified in Question 2. *Hint:* You should discuss either a change in distance between the nucleus and outer shell of electrons or a change in the number of protons in the nucleus.

4. In general, what is the trend in atomic radius as you go across a period (left to right) in Model 1? Support your answer, using examples from two periods.

5. Using your knowledge of Coulombic attraction and the structure of the atom, explain the trend in atomic radius that you identified in Question 4.

Model 1 – Main Group Elements

1							2
H							He
37							31
1312							2372
2.1							N/A
3	4	5	6	7	8	9	10
Li	Be	B	C	N	O	F	Ne
							
152	112	83	77	71	66	71	70
520	900	801	1086	1402	1314	1681	2081
1.0	1.5	2.0	2.5	3.0	3.5	4.0	N/A
11	12	13	14	15	16	17	18
Na	Mg	Al	Si	P	S	Cl	Ar
							
186	160	143	117	115	104	99	98
496	738	578	786	1011	1000	1251	1521
0.9	1.2	1.5	1.8	2.1	2.5	3.0	N/A
19	20	31	32	33	34	35	36
K	Ca	Ga	Ge	As	Se	Br	Kr
							
227	197	122	123	125	117	114	112
404	550	558	709	834	869	1008	1170
0.8	1.0	1.7	1.8	1.9	2.1	2.5	N/A

Atomic Number
Element Symbol
Electron Shell Diagram
Atomic Radius (pm)
1st Ionization Energy (kJ/mol)
Electronegativity

Note: The transition elements and f-block elements have been removed from the periodic table here to ease the analysis of the trends.

6. Locate the numbers in Model 1 that represent the ionization energy. The **ionization energy** is the amount of energy needed to remove an electron from an atom.
    a. Using your knowledge of Coulombic attraction, explain why ionization—removing an electron from an atom—takes energy.

    b. Which takes more energy, removing an electron from an atom where the nucleus has a tight hold on its electrons, or a weak hold on its electrons? Explain.

7. In general, what is the trend in ionization energy as you go down a group? Support your answer using examples from three groups.

8. Using your knowledge of Coulombic attraction and the structure of the atom, explain the trend in ionization energy that you identified in Question 7.

9. In general, what is the trend in ionization energy as you go across a period? Support your answer using examples from two periods.

10. Using your knowledge of Coulombic attraction and the structure of the atom, explain the trend in ionization energy that you identified in Question 9.

11. Atoms with loosely held electrons are usually classified as metals. They will exhibit high conductivity, ductility, and malleability because of their atomic structure. Would you expect metals to have high ionization energies or low ionization energies? Explain your answer in one to two complete sentences.

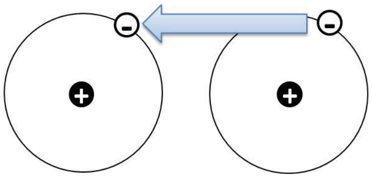
STOP

Read This!

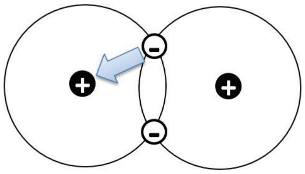
Electronegativity is a measure of the ability of an atom's nucleus to attract electrons from a different atom within a covalent bond. A higher electronegativity value correlates to a stronger pull on the electrons in a bond. This value is only theoretical. It cannot be directly measured in the lab.

12. Using the definition stated in the *Read This!* box above, select the best visual representation for electronegativity. Explain your reasoning.

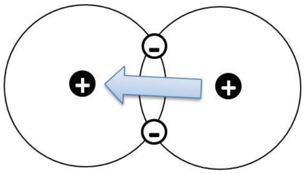
A



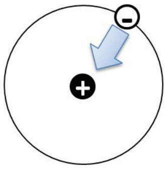
B



C



D



13. Locate the electronegativity values in Model 1.

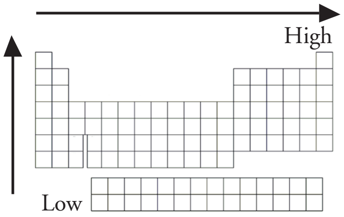
    a. What is the trend in electronegativity going down a group in Model 1?

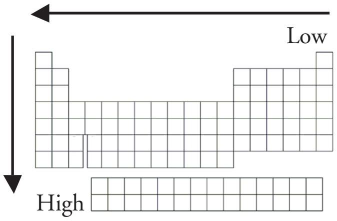
    b. Explain the existence of the trend described in part *a* in terms of atomic structure and Coulombic attraction.

    c. What is the trend in electronegativity going across a period in Model 1?

    d. Explain the existence of the trend described in part *c* in terms of atomic structure and Coulombic attraction.

14. The two diagrams below can summarize each of the three trends discussed in this activity. Write "atomic radius," "ionization energy," and "electronegativity" under the appropriate diagram.





Extension Questions

15. During this activity you may have noticed that not all of the data provided in the models followed the trends.

    a. Identify two places in Model 1 where the property listed does not fit the trend identified in this activity.

    b. Why is it still beneficial for chemists to understand as many periodic trends as they can?

    c. Propose an explanation for one of the exceptions you identified in part *a*. Use your knowledge of atomic structure and Coulombic attraction in your hypothesis.

16. Rank the following elements from **smallest to largest** electronegativity based on the trends you have discovered thus far in the periodic table: barium (atomic number 56), bromine (atomic number 35), and iron (atomic number 26). Explain your reasoning.

Naming Ionic Compounds

What are the structural units that make up ionic compounds and how are they named?

Why?

When working in chemistry, it is often convenient to write a chemical in symbols. For example we might write down the substance table salt as NaCl. In talking about chemistry however, it is a bit tacky to say "en-ay see-ell" when we want to refer to a substance. Also, in formal writing we should use the name of the compound rather than its symbols. Therefore we need to learn how to say the proper names of ionic substances.

Model 1 – Ion Charges for Selected Elements

1	H^+											
2	Li^+	Be^{2+}							N^{3-}	O^{2-}	F^{1-}	
3	Na^+	Mg^{2+}	Transition elements				Al^{3+}		P^{3-}	S^{2-}	Cl^{1-}	
4	K^+	Ca^{2+}	Fe^{2+} Fe^{3+}	Ni^{2+} Ni^{3+}	Cu^+ Cu^{2+}	Zn^{2+}					Br^{1-}	
5	Rb^+	Sr^{2+}			Ag^{1+}			Sn^{2+} Sn^{4+}			I^{1-}	
6		Ba^{2+}				Hg_2^{2+} Hg^{2+}		Pb^{2+} Pb^{4+}				

← Cations → ← Anions →

1. Based on the information in Model 1:
   a. Identify three elements that form only one cation.

   b. Identify three elements that form only one anion.

   c. Identify three elements that form more than one cation.

   d. In what region of the periodic table are these "multiple ion" elements usually located?

2. Consider the ions of potassium (K) and sulfur (S). Write chemical formulas for all possible ionic compounds involving these ions, using the simplest ratio(s) of potassium (K) and sulfur (S). Keep in mind that the sum of the charges in an ionic compound must equal zero.

3. Consider the ions of iron (Fe) and sulfur (S). Write chemical formulas for all possible ionic compounds involving these ions, using the simplest ratio(s) of iron (Fe) and sulfur (S). Keep in mind that the sum of the charges in an ionic compound must equal zero.

STOP

Model 2 – Ionic Compound Names (Metals that form one ion)

NaCl	Sodium chloride	Zn_3P_2	Zinc phosphide
CaS	Calcium sulfide	Al_2O_3	Aluminum oxide
Ag_2S	Silver sulfide	$SrCl_3$	Strontium chloride

4. Circle the symbol for the metal in each of the compounds in Model 2.

5. Which element comes first in the name and formula of the compounds in Model 2—the metal or the nonmetal?

6. Use the table of ions in Model 1 to answer the following questions:

   a. In the compound zinc phosphide, what is the charge on the zinc ion?

   b. In the compound zinc phosphide, what is the charge on the phosphide ion?

7. Explain why a 3 to 2 ratio of ions is necessary for the compound zinc phosphide.

8. The compound carbon dioxide has a name that gives you a hint as to how many oxygen atoms are in the compound. Is there anything in the name "zinc phosphide" that indicates there are three zinc and two phosphorus ions in the formula unit?

9. Is there any other ratio of zinc and phosphorus ions that could exist? For instance, could you have Zn_2P or ZnP_2? Explain your answer.

10. Explain why you don't need to specify the number of ions in the compound when you are naming ionic substances like those in Model 2.

11. Model 2 is labeled "Metals that form one ion." What other metals that also form only one ion could be included in the Model 2 list? Model 1 may be helpful in this regard.

12. Describe how the names of the nonmetal elements in Model 2 are changed when they are in their anion forms.

13. Name the following ionic compounds using what you learned from Model 2.

    Li_2O MgF_2 Al_2S_3 K_3N

14. Provide the chemical formula for each of the following ionic compounds.

Barium chloride Magnesium oxide

15. Consider the two chemical formulas you wrote in Question 3 for compounds of iron and sulfur. Would the name “iron sulfide” be sufficient to uniquely identify either of those compounds? Explain.

Read This!

When the metal in an ionic compound always forms an ion with the same charge, you need not indicate that charge as part of the compound name. However, some atoms have the ability to form more than one type of ion. This can make naming confusing. You can’t simply refer to a compound of copper and oxygen as “copper oxide.” People won’t know which compound you are referring to—CuO or Cu_2O.

Model 3 – Ionic Compound Names (Metals that form multiple ions)

Cu_2O	Copper(I) oxide	PbO	Lead(II) oxide
CuO	Copper(II) oxide	PbO_2	Lead(IV) oxide
SnF_2	Tin(II) fluoride	$FeCl_2$	Iron(II) chloride
SnF_4	Tin(IV) fluoride	$FeCl_3$	Iron(III) chloride

16. Model 3 is labeled “Metals that form multiple ions.” What other metals that form multiple ions could be included in Model 3? Model 1 may be helpful in this regard.

17. Describe the most obvious difference between the names in Model 3 and those in Model 2.

18. Do the Roman numerals in the names in Model 3 relate to the number of cations or number of anions in the formula unit? Support your answer by citing two specific examples.

19. Keeping in mind that the sum of the charges in an ionic compound must equal zero, use the chemical formulas in Model 3 to answer the following questions:

    a. Identify the charge on the copper cations in copper(I) oxide and copper(II) oxide, respectively.

    b. Identify the charge on the iron cations in iron(II) chloride and iron(III) chloride, respectively.

20. What do the Roman numerals in the compounds described in Question 19 indicate?

21. Fill in the table below using what you've learned from Model 3.

Compound	**Charge on Cation**	**Name of the Compound**
$PbCl_4$	Pb^{4+}	Lead(IV) chloride
Fe_2O_3		
SnO		
$CuBr_2$		

STOP

22. For each of the compounds in the table below, determine the type of metal in the compound and then name the compound using the correct naming method.

	Metal forms only one ion	**Metal forms multiple ions**	**Name**
$CaBr_2$			
MgO			
Ag_3N			
$SnCl_2$			
CuF_2			
K_3P			
Zn_3N_2			
HgO			

Extension Questions

Model 4 – Traditional Names for Ionic Compounds

Metals that form one ion		**Metals that form multiple ions**	
NaCl	Sodium chloride	Cu_2O	Cuprous oxide
CaS	Calcium sulfide	CuO	Cupric oxide
Ag_2S	Silver sulfide	SnF_2	Stannous fluoride
Zn_3P_2	Zinc phosphide	SnF_4	Stannic fluoride

23. Look at the traditional names in Model 4 for ionic compounds containing metals that form only one ion. What are the similarities and differences between the traditional naming system in Model 4 and the stock naming system in Model 2 for these kinds of ionic compounds?

24. Look at the traditional names in Model 4 for ionic compounds containing metals that form multiple ions. What are the similarities and differences between the traditional naming system in Model 4 and the stock naming system in Model 3 for these kinds of ionic compounds?

25. Do the "-ous" and "-ic" endings in the compound names in Model 4 refer to a particular metal ion charge? Explain.

26. Examine the traditional ion names shown below for selected metals. Write a rule for using the "-ous" and "-ic" endings for metal ions.

Cu^{2+} cupric	Fe^{3+} ferric	Sn^{4+} stannic	Pb^{4+} plumbic
Cu^{1+} cuprous	Fe^{2+} ferrous	Sn^{2+} stannous	Pb^{2+} plumbous

27. Complete the table and write the traditional name for each ionic compound.

	Metal forms only one ion	**Metal forms multiple ions**	**Name**
$CaBr_2$			
MgO			
Ag_3N			
$SnCl_2$			
CuF_2			
K_3P			
Zn_3N_2			
HgO			

28. Write the chemical formula for each ionic compound below.

aluminum bromide	
stannic sulfide	
iron(II) chloride	
lithium oxide	
plumbous oxide	

29. Throughout this activity you have developed a process for naming an ionic compound when given a formula. On a separate sheet of paper, create a flowchart of questions that you might ask yourself when naming an ionic compound.

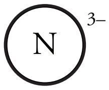
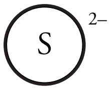
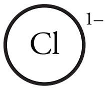
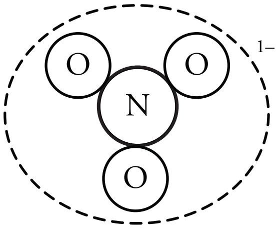
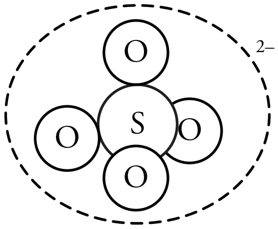
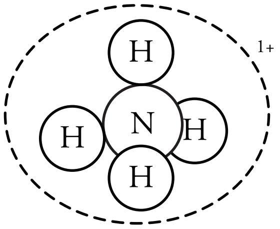
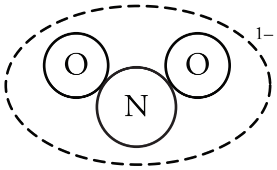
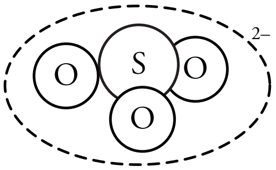
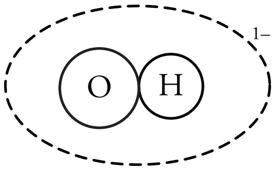
Polyatomic Ions

Can a group of atoms have a charge?

Why?

Do you know you eat a lot of “-ates”? Next time you look at a food label, read the ingredients and you will likely find a number of ingredients that end with “-ate,” such as sodium phosphate or calcium carbonate. Did you ever wonder what the chemical formulas of these ingredients look like? In this activity we will explore polyatomic ions, which are groups of atoms that carry a charge. These ions are found in our food ingredients, natural waterways, and many other chemical compounds you encounter every day.

Model 1 – Types of Ions

Monatomic Ions	Nitride 	Sulfide 	Chloride 
Polyatomic Ions	Nitrate 	Sulfate 	Ammonium 
	Nitrite 	Sulfite 	Hydroxide 

1. Use Model 1 to complete the table below.

Name of Ion	Nitride	Nitrate	Sulfate	Sulfite	Ammonium
Charge on Ion		-1			
Type and Number of Atoms			1 sulfur 4 oxygen		
Chemical Formula				SO_3^{2-}	

2. Consider the terms “monatomic” and “polyatomic” as they are used in Model 1. Write a definition for each of these terms. It may be helpful to break the words apart (*i.e.,* poly – atomic). Make sure your group comes to consensus.

   Monatomic—

   Polyatomic—

3. What types of elements (metals or nonmetals) are shown in the polyatomic ions in Model 1?

4. What type of bonds (ionic or covalent) hold the atoms together in polyatomic ions? Explain your reasoning.

5. The net charge on a sulfide ion (S^{2-}) is –2. Explain how this ion obtains its charge. Your answer should include a discussion of subatomic particles.

6. The dotted line around each polyatomic ion in Model 1 shows that the group of atoms has a charge. The charge is not on any one atom, but rather on the group of atoms as a whole. Based on your knowledge of monatomic ions, propose an explanation for the net charge on a polyatomic ion. Your answer should include a discussion of subatomic particles.

7. What are the similarities and differences between the nitrate and nitrite ions in Model 1?

8. What are the similarities and differences between the sulfate and sulfite ions in Model 1?

9. The “chlorate” polyatomic ion has a charge of –1 and is composed of one chlorine atom (the central atom) and three oxygen atoms.

   a. Draw a model of a chlorate ion.

b. Write the chemical formula for the chlorate ion, including its charge.

10. In your group discuss what "chlorite" would look like.

    a. Draw a model of a chlorite ion.

    b. Write the chemical formula for the chlorite ion, including its charge.

Model 2 – Common Polyatomic Ions

1+		1–		2–		3–	
ammonium	NH_4^{1+}	acetate	CH_3COO^{1-}	sulfate	SO_4^{2-}	phosphate	PO_4^{3-}
		hydroxide	OH^{1-}	sulfite	SO_3^{2-}		
		nitrate	NO_3^{1-}	carbonate	CO_3^{2-}		
		nitrite	NO_2^{1-}	chromate	CrO_4^{2-}		
		bicarbonate	HCO_3^{1-}	dichromate	$Cr_2O_7^{2-}$		
		permanganate	MnO_4^{1-}				
		perchlorate	ClO_4^{1-}				
		chlorate	ClO_3^{1-}				
		chlorite	ClO_2^{1-}				
		hypochlorite	ClO^{1-}				

11. What is the only polyatomic ion that is a cation?

12. How are bicarbonate and carbonate related?

13. Predict the chemical formula and charge for the bisulfate ion.

14. How are chromate and dichromate related?

15. Bromine forms polyatomic ions with structures similar to those of chlorine. Using the chlorine family of polyatomic ions as a model, predict the name of the BrO_4^{1-} ion.

16. Identify the polyatomic ion in each of these ionic compounds. Write out the name and formula of the ions including their charges.

a. $CaCO_3$ *b.* $Mg(OH)_2$ *c.* NH_4Cl

Model 3 – Ternary Ionic Compounds

Compound Name	Ion Symbols and Charges		Chemical Formula
Ammonium phosphate	NH_4^{1+}	PO_4^{3-}	$(NH_4)_3PO_4$
Barium nitrite	Ba^{2+}	NO_2^{1-}	$Ba(NO_2)_2$
Ammonium sulfate	NH_4^{1+}	SO_4^{2-}	$(NH_4)_2SO_4$
Aluminum carbonate	Al^{3+}	CO_3^{2-}	$Al_2(CO_3)_3$
Iron(III) hydroxide	Fe^{3+}	OH^{1-}	$Fe(OH)_3$
Potassium nitrate	K^{1+}	NO_3^{1-}	KNO_3

17. How are ternary ionic compounds in Model 3 different from binary ionic compounds (NaCl, MgO, $CaBr_2$, etc.) that you've seen previously? *Hint:* Consider the meaning of the word "**bi**nary."

18. Consider the compound iron(III) hydroxide in Model 3.

    a. How many hydroxide ions (OH^{1-}) are combined with an iron(III) ion (Fe^{3+})?

    b. Is your answer to part *a* the only combination of iron(III) and hydroxide that should exist in nature? Explain.

19. Consider the compound barium nitrite in Model 3.

    a. What does the subscripted "2" *inside* the parentheses of the chemical formula tell you about the compound?

$$Ba(NO_{\underset{\uparrow}{2}})_2$$

b. What does the subscripted “2” *outside* the parentheses of the chemical formula tell you about the compound?

$$\mathrm{Ba(NO_2)}_{\underset{\uparrow}{2}}$$

20. How many atoms of each element are in one formula unit of ammonium phosphate, $(NH_4)_3PO_4$?

nitrogen hydrogen phosphorus oxygen

21. A student writes the chemical formula for the ionic compound calcium hydroxide as $CaOH_2$.

a. Write the chemical formula for each ion in the compound.

Calcium: Hydroxide:

b. Why is the student’s chemical formula for the compound calcium hydroxide wrong?

22. Many of the chemical formulas in Model 3 include parentheses. Which one of the following rules summarizes the appropriate use of parentheses in ternary ionic compounds? For the three rules that do not apply in all cases, show at least one counter example from the chemical formulas in Model 3.

Parentheses are used around any ion that is used more than once in a formula unit.

Parentheses are used around any polyatomic ion.

Parentheses are used around any polyatomic ion used more than once in a formula unit.

Parentheses are only used around polyatomic anions used more than once in a formula unit.

STOP

23. Write chemical formulas for the following ternary ionic compounds.

a. Calcium sulfate *b.* Copper(II) nitrate *c.* Lithium phosphate

d. Potassium permanganate *e.* Aluminum sulfite *f.* Magnesium bicarbonate

24. Name the following ternary ionic compounds.

a. $BaSO_4$ *b.* NH_4NO_3 *c.* $K_2Cr_2O_7$

d. $Fe(NO_3)_3$ *e.* $Mg(CH_3COO)_2$ *f.* $Al_2(CO_3)_3$

Extension Questions

25. If you were asked to go to the chemical storage area and retrieve a bottle of “sulfate,” could you do so? Explain. (Assume you have permission from your teacher to go into the storage area.)

26. When asked to classify sodium acetate ($NaCH_3COO$) as either an ionic or covalent compound, a student responded with, “Sodium acetate is both ionic and covalent.” Explain why the student gave this answer.

Naming Molecular Compounds

How are the chemical formula and name of a molecular compound related?

Why?

When you began chemistry class this year, you probably already knew that the chemical formula for carbon dioxide was CO_2. Today you will find out why CO_2 is named that way. Naming chemical compounds correctly is of paramount importance. The slight difference between the names carbon monoxide (CO, a poisonous, deadly gas) and carbon dioxide (CO_2, a greenhouse gas that we exhale when we breathe out) can be the difference between life and death! In this activity you will learn the naming system for molecular compounds.

Model 1 – Molecular Compounds

Molecular Formula	Number of Atoms of First Element	Number of Atoms of Second Element	Name of Compound
ClF			Chlorine monofluoride
ClF_5	1	5	Chlorine pentafluoride
CO			Carbon monoxide
CO_2			Carbon dioxide
Cl_2O			Dichlorine monoxide
PCl_5			Phosphorus pentachlroride
N_2O_5			Dinitrogen pentoxide

1. Fill in the table to indicate the number of atoms of each type in the molecular formula.
2. Examine the molecular formulas given in Model 1 for various molecular compounds.
   a. How many different *elements* are present in each compound shown?

   b. Do the compounds combine metals with metals, metals with nonmetals, or nonmetals with nonmetals?

   c. Based on your answer to *b*, what type of bonding must be involved in molecular compounds?

3. Find all of the compounds in Model 1 that have chlorine and fluorine in them. Explain why the name "chlorine fluoride" is not sufficient to identify a specific compound.
4. Assuming that the name of the compound gives a clue to its molecular formula, predict how many atoms each of these prefixes indicates, and provide two examples.

   mono-

   di-

   penta-

Model 2 – Prefixes and Suffixes

Prefix	Numerical Value
mono-	
di-	
tri-	
tetra-	
penta-	
hexa-	
hepta-	
octa-	
nona-	
deca-	

Molecular Formula	Name of Compound
BCl_3	Boron trichloride
SF_6	Sulfur hexafluoride
IF_7	Iodine heptafluoride
NI_3	Nitrogen triiodide
N_2O_4	Dinitrogen tetroxide
Cl_2O	Dichlorine monoxide
P_4O_{10}	Tetraphosphorus decoxide
B_5H_9	Pentaboron nonahydride
Br_3O_8	Tribromine octoxide
ClF	Chlorine monofluoride

5. Examine the prefixes in Model 2. Fill in the numerical value that corresponds to each prefix.
6. What suffix (ending) do all the compound names in Model 2 have in common?
7. Carefully examine the names of the compounds in Model 2. When is a prefix NOT used in front of the name of an element?
8. Consider the compound NO.
   - *a.* Which element, nitrogen or oxygen, would require a prefix in the molecule name? Explain your answer.
   - *b.* Name the molecule NO.

9. Find two compounds in Model 2 that contain a subscript of "4" in their molecular formula.
   - *a.* List the formulas and names for the two compounds.
   - *b.* What is different about the spelling of the prefix meaning "four" in these two names?

10. Find two compounds in Model 2 that contain the prefix "mono-" in their names.
    a. List the formulas and names for the two compounds.

    b. What is different about the spelling of the prefix meaning "one" in these two names?

11. Identify any remaining names of compounds in Model 2 where the prefixes that do not exactly match the spelling shown in the prefix table.

12. Use your answers to Questions 9–11 to write a guideline for how and when to modify a prefix name for a molecular compound. Come to a consensus within your group.

13. Would the guideline you wrote for Question 12 give you the correct name for NI_3 as it is given in Model 2? If not, modify your guideline to include this example.

14. All of the compounds listed in Model 2 are binary molecular compounds. Compounds such as CH_3OH or PF_2Cl_3 are not binary, and compounds such as NaCl or $CaCl_2$ are not molecular. Propose a definition for "binary molecular compounds."

15. Collaborate with your group members to write a list of rules for recognizing and naming binary molecular compounds from their chemical formulas.

STOP

16. For each of the following compounds, indicate whether or not your naming rules from Question 15 will apply. If not, explain why the naming rules do not apply.

FeI_3 ICl_5 $HBrO_4$

17. Using the rules your group developed in Question 15, name each of the following molecular compounds.

Molecular Formula	**Molecule Name**
PBr_3	
SCl_4	
N_2F_2	
SO_3	
BrF	

18. Write molecular formulas for the following compounds.

Molecular Formula	**Molecule Name**
	Disulfur decafluoride
	Carbon tetrachloride
	Oxygen difluoride
	Dinitrogen trioxide
	Tetraphosphorus heptasulfide

STOP

Extension Questions

19. This activity focused on molecular (covalent) compounds, while an earlier activity addressed ionic compounds. Notice that the formulas for both types of compounds can look very similar, even though their names are quite different:

Chemical Formula	**Type of Compound/Bonding**	**Compound Name**
MgF_2	Ionic	Magnesium fluoride
CuF_2	Ionic	Copper(II) fluoride
SF_2	Molecular (covalent)	Sulfur difluoride
NaBr	Ionic	Sodium bromide
AuBr	Ionic	Gold(I) bromide
IBr	Molecular (covalent)	Iodine monobromide

Identify two differences between the names or formulas for ionic compounds versus those for binary molecular compounds. Also identify two similarities.

	Names and Formulas of Ionic Compounds	**Names and Formula of Molecular (Covalent) Compounds**
Differences		
Similarities		

20. Use complete sentences to explain why $AlCl_3$ is called "aluminum chloride" (no prefix required), but BCl_3 is called "boron trichloride."

21. In the table below, first identify the type of bonding present in each compounds. Then fill in the missing name or formula for each compound using the appropriate set of rules.

Chemical Formula	**Type of Compound/Bonding**	**Compound Name**
CS_2		
PbI_2		
$BaCl_2$		
Se_2S_6		
		Xenon tetrafluoride
		Sodium phosphide
		Dinitrogen pentoxide
		Cobalt(III) bromide

Naming Acids

What makes an acid unique and how are acids named?

Why?

A variety of acids are used in foods, industry, and research. Acids are covalently bonded molecules, but when they are put into water they produce ions. One of the ions produced is always H^+, which immediately combines with a water molecule to form the hydronium ion (H_3O^+). The H_3O^+ ion is what defines the acidic properties of a substance. Because of their special classification, acids have a naming system different from ionic or other molecular (covalent) compounds.

Model 1 – Binary Acids

Acid	Name of acid in aqueous solution	Cation (+)*	Anion (–)
HCl	Hydrochloric acid	H_3O^+	Cl^{1-}
HBr	Hydrobromic acid		
H_2S	Hydrosulfuric acid	$2H_3O^+$	S^{2-}
HF	Hydrofluoric acid		

*Hydrogen ions (H^+) join with water molecules in solution to form hydronium ions, H_3O^+.

1. Complete the cation and anion columns of the table in Model 1. Be careful to show the charges on the ions.
2. Why does hydrosulfuric acid contain two hydrogens?
3. Look at the formulas and names of the binary acids in Model 1.
   a. What prefix is used at the beginning of the name for all binary acids?
   b. What suffix is used at the end of the name for all binary acids?
4. The prefix "bi" means "two." Propose a reason that the acids in Model 1 are all referred to as "binary" acids.
5. Write a rule for naming binary acids.

Model 2 – Ternary Acids (Oxyacids)

Acid	Name of Acid in Aqueous Solution	Cation (+)	Polyatomic Anion (–)	Polyatomic Anion Name
$HClO_3$	Chloric acid	H_3O^+		
H_2SO_3	Sulfurous acid			
H_2SO_4	Sulfuric acid			Sulfate
H_3PO_3	Phosphorous acid	H_3O^+		Phosphite
H_3PO_4	Phosphoric acid		PO_4^{3-}	
HNO_3	Nitric acid			
HNO_2	Nitrous acid		NO_2^{1-}	Nitrite
H_2CO_3	Carbonic acid			

6. Look at the formulas of the ternary acids in Model 2.

   a. How are ternary acids different from binary acids in their structure?

   b. What number do you think the prefix "ter-" refers to?

7. When ternary acids are mixed with water, ions will form. Fill in the table above with the formulas and names of the anions.

8. Examine the pairs of ternary acids in Model 2 that contain sulfur, phosphorus, and nitrogen. Each pair has one acid that ends in "-ic" and another that ends in "-ous." These endings are related to the name of the polyatomic anion found in the acid ("-ate" or "-ite"). Complete the statements below with the correct acid name ending.

   Polyatomic anion ending is "-ate" → acid name ending is ________.

   Polyatomic anion ending is "-ite" → acid name ending is ________.

9. If the prefix "hydro-" were used to name a ternary acid, what problem would this create when naming $HClO_3$?

10. Write a rule for naming ternary acids.

11. Predict the formula for chlorous acid.

12. Circle the acid(s) below that would be named beginning with the prefix "hydro-."

    H_2SO_3 HF H_2S H_2CO_3 HNO_2

Extension Questions

Model 3 – Halogen Oxyacid Acid Families

Acid	Name of Acid	Cation (+)	Anion (–)	Anion Name
$HClO_4$	Perchloric acid			Perchlorate
$HClO_3$	Chloric acid	H_3O^+		
$HClO_2$	Chlorous acid			Chlorite
HClO	Hypochlorous acid			
$HBrO_4$				Perbromate
HIO_3				
HFO_2				
HIO			IO^-	Hypoiodite

13. Write the formulas of the cations and anions for each acid in the table in Model 3.

14. Consider the names of the oxyacids in Model 3 that contain chlorine. All halogens form similar oxyacids that use the same naming convention. Fill in the names of the halogen oxyacids to complete the table.

15. The table below includes both binary and ternary acids. Using what you have learned in this activity, fill in the missing formula and name for the anion in each acid, and give the formula of the acid.

Acid name	Anion	Anion Name	Acid Formula
Hydroiodic acid			
Chlorous acid			
Hypobromous acid			
Phosphoric acid			
Sulfurous acid			

Molecular Geometry

How can molecular shapes be predicted using the VSEPR theory?

Why?

When you draw a Lewis structure for a molecule on paper, you are making a two-dimensional representation of the atoms. In reality however, molecules are not flat—they are *three*-dimensional. The true shape of a molecule is important because it determines many physical and chemical properties for the substance. In this activity you will learn how to predict molecular shapes.

Model 1 – Lewis Structures

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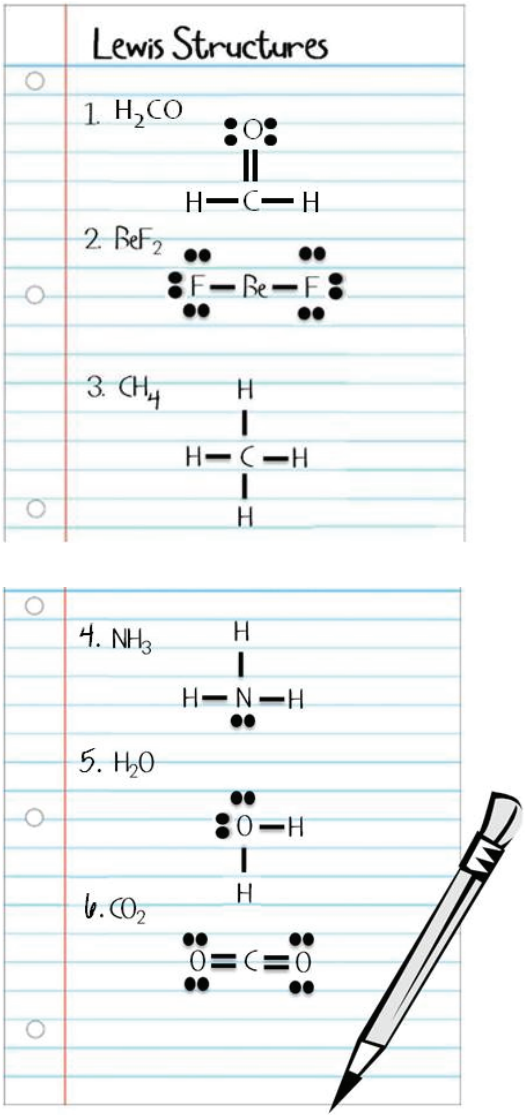
<td rowspan="6">

Lone pair = ••</td>
<td>H_2CO
3 electron domains
(3 bonding, 0 nonbonding)</td>
<td>3-D Molecular Shape</td>
</tr>
<tr>
<td>BeF_2
2 electron domains
(2 bonding, 0 nonbonding)</td>
<td></td>
</tr>
<tr>
<td>CH_4
4 electron domains
(4 bonding, 0 nonbonding)</td>
<td></td>
</tr>
<tr>
<td>NH_3
4 electron domains
(3 bonding, 1 nonbonding)</td>
<td></td>
</tr>
<tr>
<td>H_2O
4 electron domains
(2 bonding, 2 nonbonding)</td>
<td></td>
</tr>
<tr>
<td>CO_2
2 electron domains
(2 bonding, 0 nonbonding)</td>
<td></td>
</tr>
</table>

1. Name the type of structures shown in the left-hand column of Model 1.

2. Examine the drawings in Model 1.
    a. What does a solid line between two element symbols represent in the drawings of the molecules?
    b. What subatomic particles (protons, neutrons or electrons) make up these solid lines?
    c. What does a pair of dots represent in the drawing of the molecules?
    d. What subatomic particle (protons, neutrons or electrons) makes up each dot?

3. In the English language, what does the word "domain" mean? (Your group must come to consensus on this question.)

4. Which molecules in Model 1 have four electron domains? Circle or highlight the four electron domains in the Lewis structure for each molecule that you identified.

5. Which molecules in Model 1 have two electron domains? Circle or highlight the two electron domains in the Lewis structure for each molecule that you identified.

6. Which molecule in Model 1 has three electron domains? Circle or highlight the three electron domains in the Lewis structure for the molecule that you identified.

7. When determining the number of electron domains in a Lewis structure, which of the following should you count? Find evidence from Model 1 to support your answers.
    a. Bonds on the center atom
    b. Lone pairs on the center atom
    c. Total number of atoms in the molecule
    d. Lone pairs on peripheral atoms

8. When determining the number of electron domains in a Lewis structure, do you count double bonds as one domain or two domains? Find evidence to support your answer from Model 1.

9. Explain the difference between a **bonding electron domain** and a **nonbonding electron domain** using the examples in Model 1.

10. Circle the correct word or phrase to complete the sentences:

    Pairs of electrons will (attract/repel) each other.

    Two bonds on the same atom will try to get as (close to/far from) each other as possible.

    A lone pair of electrons and a bonded pair of electrons will (push away from/move toward) each other.

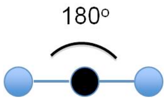
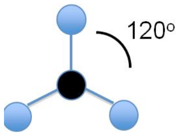
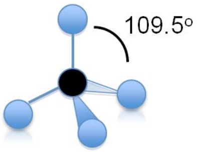
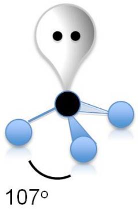
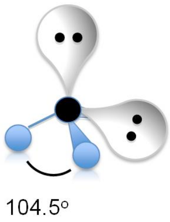
Read This!

The **VSEPR (Valence Shell Electron Pair Repulsion) Theory** helps predict the shapes of molecules and is based on the premise that electrons around a central atom repel each other. **Electron domains** are areas of high electron density such as bonds (single, double or triple) and lone-pairs of electrons. In simple terms VSEPR means that all electron bonding domains and electron nonbonding domains around a central atom need to be positioned as far apart as possible in *three-dimensional* space.

11. VSEPR theory specifies "valence shell" electrons. Explain why these are the most critical electrons for determining molecular shape based on your exploration of Model 1.

12. In the VSEPR theory, what is repelling what?

13. Based on the information in the *Read This!* section, sketch one of the molecular shapes shown below in each of the boxes provided in Model 1.

Three-Dimensional Molecular Shapes	Linear 	Trigonal planar 
Tetrahedral 	Pyramidal 	Bent 

14. Often we draw Lewis structures with 90° bond angles. Do any of the molecular shapes in Model 1 have 90° bond angles?

15. Are the bond angles in the three-dimensional molecules generally larger or smaller than those shown in the Lewis structures drawn on notebook paper?

16. Why is it possible to get larger angles separating electron domains in three-dimensions versus two-dimensions?

17. Identify the three molecules shown in Model 1 that have four electron domains each.
    - *a.* What happens to the size of the bond angle(s) in a molecule as the number of lone pairs on the central atom increases?
    - *b.* Discuss in your group some possible explanations for the trend in part *a*. Your presenter should be ready to present to the class one or two of your hypotheses for full class discussion.

STOP

18. A student does not "waste" his time drawing a Lewis structure before determining the shape of PF_3. The student thinks that the shape of PF_3 must be trigonal planar because there are three fluorine atoms bonded to the central phosphorus atom.
    - *a.* Draw the Lewis structure for PF_3.
    - *b.* Was the student's answer for the shape of a PF_3 molecule correct? Explain.
    - *c.* Why is it important to draw the Lewis structure for a molecule before identifying the shape of the molecule?

19. Complete the following chart:

Molecule	**Lewis Structure**	**3-D Drawing**	**Name of 3-D Shape**	**Bond Angle**
H_2S				
PH_3				
CCl_4				
CS_2				

STOP

Extension Question

20. Ozone, O_3, is not a linear molecule. Actually it is bent with an angle that is a little less than 120°.

    a. Draw the Lewis structure of ozone, O_3.

    b. Describe why ozone has a bent shape instead of a linear shape.

    c. Describe why ozone's bond angle is larger than that of water, H_2O.

Types of Chemical Reactions

Do atoms rearrange in predictable patterns during chemical reactions?

Why?

Recognizing patterns allows us to predict future behavior. Weather experts use patterns to predict dangerous storms so people can get their families to safety. Political analysts use patterns to predict election outcomes. Similarly, chemists classify chemical equations according to their patterns to help predict products of unknown but similar chemical reactions.

Model 1 – Types of Reactions

Set A ___________________________

$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$
$MgO(s)+ H_2O(l) \rightarrow Mg(OH)_2(aq)$
$P_2O_5(g) + 3H_2O(l) \rightarrow 2H_3PO_4(aq)$
$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$

Set B ___________________________

$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$
$8Li_2S(s) \rightarrow 16Li(s) + S_8(s)$
$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$
$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$
$2Na_2O_2(s) \rightarrow 2Na_2O(s) + O_2(g)$
$(NH_4)_2CO_3(s) \rightarrow 2NH_3(g) + H_2O(l) + CO_2(g)$

Set C ___________________________

$2FeCl_3(aq) + 3Zn(s) \rightarrow 2Fe(s) + 3ZnCl_2(aq)$
$2Al(NO_3)_3(aq) + 3Ca(s) \rightarrow 3Ca(NO_3)_2(aq) + 2Al(s)$
$Mg(s) + CuSO_4(aq) \rightarrow MgSO_4(aq) + Cu(s)$
$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$
$Cl_2(g) + 2NaBr(aq) \rightarrow 2NaCl(aq) + Br_2(l)$
$ZnBr_2(aq) + F_2(g) \rightarrow ZnF_2(aq) + Br_2(l)$

Set D ___________________________

$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$
$2HNO_3(aq) + Mg(OH)_2(aq) \rightarrow Mg(NO_3)_2(aq) + 2H_2O(l)$
$Na_2CO_3(aq) + CaCl_2(aq) \rightarrow CaCO_3(s) + 2NaCl(aq)$
$FeS(s) + 2HCl(aq) \rightarrow H_2S(g) + FeCl_2(aq)$
$HCl(aq) + NaOH(aq) \rightarrow H_2O(l) + NaCl(aq)$
$FeBr_3(aq) + K_3PO_4(aq) \rightarrow FePO_4(s) + 3KBr(aq)$

1. The chemical equations in Model 1 contain the phase notations (s), (l), (g), and (aq). Match each symbol with its meaning.

   dissolved in water   liquid   solid   gas

2. Based on the examples provided, which set(s) of reactions in Model 1 typically involve ions in solution (A, B, C or D)?

3. Based on the examples provided, which set(s) of reactions in Model 1 typically involve gases and/or solids?

4. Match each description below to one of the reactions sets (A, B, C or D) from Model 1.

____________________ Ionic compounds dissolved in water switch partners.

____________________ One compound breaks into elements or smaller compounds.

____________________ Two or more elements or compounds combine to form one product.

____________________ Part of an ionic compound is removed and replaced by a new element.

5. Define the following terms as they are commonly used in the English language.

Synthesis—

Decomposition—

Replacement—

6. The four sets of chemical reactions shown in Model 1 have the following general names. Discuss within your group which name belongs to which set of chemical reactions. Write the name in the appropriate place in Model 1.

Single Replacement Reaction	Synthesis Reaction
Double Replacement Reaction	Decomposition Reaction

7. Can two elements be used as reactants for a synthesis reactions? If yes, give at least one example from Model 1 to support your answer.

8. Can two compounds be used as reactants for a synthesis reaction? If yes, give at least one example from Model 1 to support your answer.

9. What types of substances (elements or compounds) are seen in the products of decomposition reactions? Use examples from Model 1 to support your answer.

10. In single replacement reactions, do any of the atoms change their charge? If yes, use an example from Model 1 to describe the changes that take place.

11. In double replacement reactions, do any of the atoms change their charge? If yes, use an example from Model 1 to describe the changes that take place.

12. Choose one example from the set of synthesis reactions in Model 1.

    a. Write the chemical reaction in reverse.

    b. Label the reaction written in part *a* with one of the reaction types in Model 1.

13. Identify each of the reactions below as synthesis (S), decomposition (D), single replacement (SR) or double replacement (DR).

_____ $K_2O(s) + H_2O(l) \rightarrow 2KOH(aq)$

_____ $2MgCl_2(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + MgCO_3(s)$

_____ $2Al_2O_3(s) \rightarrow 4Al(s) + 3O_2(g)$

_____ $Cu(NO_3)_2(aq) + Zn(s) \rightarrow Cu(s) + Zn(NO_3)_2(aq)$

_____ $H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

_____ $2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$

_____ $2O_2(g) + N_2(g) \rightarrow N_2O_4(g)$

_____ $2NaF(s) \rightarrow 2Na(s) + F_2(g)$

14. A student writes the following incorrect chemical equation for the synthesis of magnesium oxide.

    $Mg + O_2 \rightarrow MgO_2$

    Another student writes the following incorrect synthesis reaction.

    $Mg + O \rightarrow MgO$

    a. What is the correct formula for magnesium oxide? *Hint:* Magnesium oxide is an ionic compound.

    b. What is the correct formula for elemental oxygen?

    c. Describe the error made by the first student.

    d. Describe the error made by the second student.

    e. Write the correct balanced chemical equation for the synthesis of magnesium oxide.

15. A student writes the following *incorrect* chemical equation for a single replacement reaction between lithium bromide and fluorine.

    $2LiBr(aq) + F_2(g) \rightarrow 2Li(s) + 2FBr(g)$

    a. In a single replacement reaction, part of an ionic compound is removed and replaced by a new element. What element will fluorine replace in lithium bromide? *Hint:* What is the most common ionic form of fluorine?

    b. What is wrong with the student's prediction of the products in the above reaction?

    c. Predict the products and write the correct balanced equation for the single replacement reaction between lithium bromide and fluorine.

16. A student writes the following incorrect chemical equation for a double replacement reaction between iron(III) bromide and sodium hydroxide solutions.

    $FeBr_3(aq) + NaOH(aq) \rightarrow FeOH(s) + NaBr_3(aq)$

    a. What is wrong with the chemical formula(s) of the product(s) predicted by this student?

    b. Write the correct equation for the double replacement reaction between iron(III) bromide and sodium hydroxide.

17. Consider the following chemical reaction written as a **word equation**.

    diphosphorus pentoxide + water → phosphoric acid

    a. Identify the type of chemical reaction from Model 1 that would describe this reaction.

    b. Write chemical formulas under the names of the substances in the word equation.

    c. Balance the chemical equation.

STOP

Read This!

Chemists use their knowledge of synthesis, decomposition, single replacement, and double replacement to predict what will happen in chemical reactions. When predicting the products for a reaction it is important to remember that atoms or ions will only combine in ways that make them stable, otherwise the reaction will not happen under normal conditions. This means that it is important to pay attention to ion charges, the natural state of elements, and the formulas of common molecular substances like carbon dioxide and water. It is only *after* predicting the products and writing the correct formulas that a chemist would then apply the law of conservation of mass and balance the chemical equation using coefficients as needed.

18. Use your understanding of common chemical reactions to predict the products for the following reactions. Writing a word equation may be helpful. Balance the chemical equations *after* you have written the correct chemical formulas for all of the reactants and products.

    a. $Al(s) + N_2(g) \rightarrow$

    b. dinitrogen oxide(g) →

    c. $SrCl_2(aq) + 2AgNO_3(aq) \rightarrow$

    d. chromium(III) nitrate(aq) + zinc chloride(aq) →

    e. $2Na(s) + Cl_2(g) \rightarrow$

    f. $Zn(s) + 2HCl(aq) \rightarrow$

Extension Questions

Model 2 – Combustion Reactions

$2C_8H_{18}(g) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g)$ (C_8H_{18} = octane—gasoline component)

$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$ (C_4H_{10} = butane—lighter fuel)

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ (CH_4 = methane—natural gas)

19. What are the products in all of the combustion reactions in Model 2?

20. What reactant is common in all of the combustion reactions in Model 2?

21. The "fuel" in most combustion reactions is a **hydrocarbon**. Using the examples in Model 2, write a description for the classification of substances known as hydrocarbons.

22. Predict the products of the following combustion reactions, and balance each reaction equation.

    a. $C_5H_{12} + 8O_2 \rightarrow$

    b. $2C_2H_2 + 5O_2 \rightarrow$

23. Compounds such as isopropyl alcohol (C_3H_7OH) and glucose ($C_6H_{12}O_6$) can also undergo combustion in a similar way. Predict the products of the following combustion reactions, and balance each reaction equation.

    a. $C_3H_7OH + O_2 \rightarrow$

    b. $C_6H_{12}O_6 + O_2 \rightarrow$

24. For each of the reaction types in Model 1, explain why a combustion reaction CANNOT be classified as that type. Use a complete sentence in each answer.

Relative Mass and the Mole

How can atoms be counted using a balance?

Why?

Consider the following equation for a chemical reaction: $2H_2 + O_2 \rightarrow 2H_2O$

This can be interpreted as two molecules of hydrogen and one molecule of oxygen combining to form two water molecules. But how often do chemists limit their reactions to one or two molecules? Usually a reaction is done with an unimaginable number of molecules. How then do chemists know they have the right mix? The molecules need to be quickly counted! How do we count molecules? The answer is the unit called the **mole**. This activity will start by considering two egg farmers (a chicken farmer and a quail farmer). They produce such large numbers of eggs that they can't count them all individually, so they count in dozens of eggs in some cases, while in other cases they use mass. Weighing is often easier than counting!

Model 1 – Eggs

Chicken		**Quail**		**Ratio of numbers of eggs**	**Ratio of masses of eggs**
Number of eggs in the sample	Mass of the sample	Number of eggs in the sample	Mass of the sample		
1	37.44 g	1	2.34 g	1 : 1	16 : 1
10		10			
438		438			
1 dozen		1 dozen			
1 million		1 million			

1. Consider the data in Model 1.
   a. What is the mass of a standard chicken egg?
   b. What is the mass of a standard quail egg?
   c. Show mathematically how the 16:1 ratio of masses was calculated in the last column of Model 1.
2. Use a calculator to complete the table in Model 1. Divide the work among group members. Reduce all ratios to the lowest whole numbers possible.

3. Imagine you have two baskets—one filled with quail eggs and one filled with the same number of chicken eggs.
   a. Which basket would be heavier?
   b. How many times heavier would that basket be?
   c. Explain mathematically how it is possible for you to answer part *b* with confidence, even though you don't know the actual number of eggs.

4. A farmer weighs out 32.0 kg of chicken eggs.
   a. What mass of quail eggs would he need to weigh out to have the same number of eggs in both samples?
   b. If the farmer had weighed out 32.0 pounds of chicken eggs (rather than kilograms), what mass of quail eggs would he need to weigh out to have the same number of eggs in both samples?

5. A farmer makes up a new counting unit called a "cluckster."
   a. If the farmer had 3 clucksters of chicken eggs and 3 clucksters of quail eggs, what could you say about the ratio of their masses?
   b. Does it matter in this problem how many eggs are in a "cluckster"? Explain.

STOP

Read This!

Let's take what we learned in the egg model and apply it to atoms. Like eggs, atoms of the same element may have slightly different masses (remember isotopes). The periodic table lists an average atomic mass for the atoms in a sample of each element. These masses are recorded in "atomic mass units" where 1 amu is approximately equal to the mass of a proton (or neutron).

Model 2 – Atoms

Oxygen		**Sulfur**		**Ratio of numbers of atoms**	**Ratio of masses of atoms**
Number of atoms in the sample	Mass of the sample	Number of atoms in the sample	Mass of the sample		
1	16.00 amu	1	32.00 amu		
10		10			
1 dozen		1 dozen			
1 million		1 million			
1 mole	16.00 grams	1 mole	32.00 grams		

Note: The masses shown for oxygen and sulfur have been rounded to make the arithmetic a bit easier.

6. What is the ratio of the mass of an oxygen atom to the mass of a sulfur atom?

7. Fill in the table in Model 2 in a similar fashion to the eggs table in Model 1. Divide the work evenly among group members. Reduce all ratios to the lowest whole numbers possible.

8. Circle the phrase below that completes the sentence.

   When two samples contain the same number of atoms __________________________.

   the masses of the samples will be equal.

   the ratio of the sample masses will be equal to the ratio of the atom's masses.

   the masses are unrelated.

9. Explain why it is not necessary to know how many atoms are in "1 mole" to finish the last row of the table in Model 2.

10. How would the number of oxygen atoms in a 16.00 lbs sample compare to the number of sulfur atoms in a 32.00 lbs sample?

11. In the front of the room, there is a bottle that contains a 32.00 g sample of sulfur. This is 1 mole of sulfur. Estimate how many atoms are in the bottle. Your group must reach consensus.

Read This!

A long time ago chemists discovered what you have just discovered: *The relative masses of the elements can be used to "count" atoms.* If you measure out a sample equal to an atom's atomic mass in grams, you always end up with the same number of atoms. Chemists call that quantity the **mole**—a quantity of any sample whose mass is equal to its atomic mass in grams.

Model 3 – Molar Mass

Average Mass of a Single Particle	
1 atom of hydrogen (H)	1.01 amu
1 atom of copper (Cu)	63.55 amu
1 molecule of oxygen (O_2)	32.01 amu
1 molecule of water (H_2O)	18.02 amu
1 formula unit of sodium chloride (NaCl)	58.44 amu

Average Mass of One Mole of Particles (Molar Mass)	
1 mole of hydrogen atoms (H)	1.01 g
1 mole of copper atoms (Cu)	63.55 g
1 mole of oxygen molecules (O_2)	32.01 g
1 mole of water molecules (H_2O)	18.02 g
1 mole of sodium chloride formula units (NaCl)	58.44 g

12. Look at a periodic table. What number in each element box would a chemist use to find the values in the "Average Mass of a Single Particle" column in Model 3?

13. How is the mass of a single particle changed to get the mass of one mole of particles?

14. Which sample contains more atoms, 18.016 amu of water or 18.016 g of water? Explain.

15. If the formula mass of iron(II) sulfate ($FeSO_4$) is 151.9 amu, what is the molar mass of iron(II) sulfate?

16. Use a periodic table to calculate the molar mass of ammonia (NH_3).

17. How would the number of atoms in a 1.01 g sample of hydrogen compare to the number of atoms in a 63.55 g sample of copper?

Read This!

So how many "things" are in a mole? By estimating the size of atoms and taking volume measurements of 1 mole samples scientists can estimate that

1 mole = $6.022 \rightarrow 10^{23}$ particles or 602 200 000 000 000 000 000 000 particles

(More than you could count in a lifetime!)

This number is called Avogadro's number, named after Amedeo Avogadro.

18. Fill in the blanks below using a periodic table. Be sure to include units of g or amu on all masses.

1 atom of helium has a mass of ____________.

1 mole of helium contains ____________________ atoms, and has a mass of ____________.

1 formula unit of calcium chloride ($CaCl_2$) has a mass of ____________.

1 mole of $CaCl_2$ contains ___________________ formula units, and has a mass of ____________.

Extension Questions

19. Use a periodic table to answer the following questions.
    - *a.* Fluorine gas consists of diatomic molecules of fluorine (F_2). How many molecules of fluorine are in one mole of fluorine?
    - *b.* What is the mass of 1 mole of fluorine gas?
    - *c.* How many *atoms* of fluorine are in this sample? Show your work.

20. The mass of one mole of lead (Pb) atoms is 207.2 g. Use a proportion to calculate the number of lead atoms in a 15.00 g sample of lead.

21. What is the mathematical relationship between atomic mass units (amu) and grams (g)?

    1 gram = ______________ amu

Mole Ratios

How can the coefficients in a chemical equation be interpreted?

Why?

A balanced chemical equation can tell us the number of reactant and product particles (ions, atoms, molecules or formula units) that are necessary to conserve mass during a chemical reaction. Typically when we balance the chemical equation we think in terms of individual particles. However, in real life the reaction represented by an equation occurs an unimaginable number of times. Short of writing very large numbers (10^{23} or larger) in front of each chemical in the equation, how can we interpret chemical equations so that they more realistically represent what is happening in real life? In this activity you will explore the different ways a chemical reaction can be interpreted.

Model 1 – A Chemical Reaction

$$\boxed{N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)}$$

1. Consider the reaction in Model 1.
   a. What are the coefficients for each of the following substances in the reaction?

   N_2 H_2 NH_3

   b. Draw particle models below to illustrate the reaction in Model 1.

2. Consider each situation below as it relates to the reaction in Model 1.
   a. Calculate the amount of reactants consumed and products made.
   b. Record the ratio of N_2 to H_2 to NH_3. Reduce the ratio to the lowest whole numbers possible.

	N_2 Consumed	**H_2 Consumed**	**NH_3 Produced**	**Ratio N_2:H_2:NH_3 (reduced)**
For a single reaction, how many molecules of each substance would be consumed or produced?				
If the reaction occurred one hundred times, how many molecules would be consumed or produced?				
If the reaction occurred 538 times, how many molecules would be consumed or produced?				

3. Refer to the data table in Question 2.

   a. How do the reduced ratios in the last column compare to the coefficients in the reaction shown in Model 1?

   b. Use mathematical concepts to explain how your answer in part *a* is possible.

4. Even 538 is a small number of molecules to use in a reaction. Typically chemists use much larger numbers of molecules. (Recall that one mole is equal to 6.02×10^{23} particles.) Consider each situation below as it relates to the reaction in Model 1: $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$.

   a. Calculate the amount of reactants consumed and products made.

   b. Record the ratio of N_2 to H_2 to NH_3. Reduce the ratio to the lowest whole number possible.

	N_2 Consumed	**H_2 Consumed**	**NH_3 Produced**	**Ratio N_2:H_2:NH_3**
If the reaction occurred 6.02×10^{23} times, how many molecules would be consumed or produced?				
How many ***moles*** of each substance would be consumed or produced in the previous situation?				

5. Refer to the data table in Question 4.

   a. How do the reduced ratios in the last column compare to the coefficients in the reaction in Model 1?

   b. Use mathematical concepts to explain how your answer in part *a* is possible.

6. The ratio obtained from the coefficients in a balanced chemical equation is called the **mole ratio**.

   a. What is the mole ratio for the reaction in Model 1?

   b. Explain why this ratio is called the mole ratio?

7. Use the mole ratio from the balanced chemical equation in Model 1, $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$, to solve the following problems. *Hint:* Set up proportions.

   a. How many moles of nitrogen would be needed to make 10.0 moles of ammonia?

   b. How many moles of ammonia could be made by completely reacting 9.00 moles of hydrogen?

   c. How many moles of hydrogen would be needed to react completely with 7.41 moles of nitrogen?

8. Consider this situation as it relates to the reaction in Model 1, $N_2(g) + 3H_2(g) \rightarrow 2\ NH_3(g)$.

   a. Calculate the amounts of reactants consumed and the amount of product made.

   b. Record the mass ratio of N_2 to H_2 to NH_3. Reduce the ratio to the lowest whole numbers possible.

	N_2 Consumed	**H_2 Consumed**	**NH_3 Produced**	**Mass Ratio N_2:H_2:NH_3**
How many grams of each substance would be consumed or produced in the situation in Question 4?				

9. Refer to the data table in Question 8.

   a. Can the mole ratio from a balanced chemical equation be interpreted as a ratio of masses?

   b. Use mathematical concepts to explain how your answer in part *a* is possible.

10. As a group, develop a plan to solve the following problem. Remember that the mole ratio cannot be used directly in this situation. *Note:* You do not need to do the actual calculation here.

    "What mass of nitrogen is needed to produce 30.0 g of ammonia?"

Model 2 – Proposed Calculations for Mass of NH_3 to Mass of N_2

Toby's Method

$$\frac{\text{x grams}}{30.0\text{ g}} = \frac{1\text{ mole } N_2}{2\text{ moles } NH_3} \rightarrow \quad x = \underline{\hspace{2cm}}\text{ g } N_2$$

Rachel's Method

$$30.0\text{ g } NH_3 \times \frac{1\text{ mole } NH_3}{17.0\text{ g } NH_3} = \underline{\hspace{2cm}}\text{ moles } NH_3$$

$$\frac{\text{x mole } N_2}{\underline{\hspace{1.5cm}}\text{ mole } NH_3} = \frac{1\text{ mole } N_2}{2\text{ moles } NH_3} \rightarrow \quad x = \underline{\hspace{2cm}}\text{ moles } N_2$$

$$\underline{\hspace{2cm}}\text{ mole } N_2 \times \frac{28.0\text{ g } N_2}{1\text{ mole } N_2} = \underline{\hspace{2cm}}\text{ g } N_2$$

Jerry's Method

$$30.0\text{ g } NH_3 \times \frac{1\text{ mole } NH_3}{17.0\text{ g } NH_3} \times \frac{1\text{ mole } N_2}{2\text{ moles } NH_3} \times \frac{28.0\text{ g } N_2}{1\text{ mole } N_2} = \underline{\hspace{2cm}}\text{ g } N_2$$

11. Model 2 shows three proposed calculations to solve the problem in Question 10. Complete the calculations in Model 2 by filling in the underlined values.
12. Which method does not use the mole ratio in an appropriate manner? Explain.
13. Two of the methods in Model 2 give the same answer. Show that they are mathematically equivalent methods.
14. Use either Rachel or Jerry's method from Model 2 to calculate the mass of hydrogen needed to make 30.0 g of ammonia. $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

Extension Questions

15. One mole of any gas will occupy 22.4 L of volume at standard temperature and pressure (STP).

    Consider this situation as it relates to the reaction in Model 1: $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

    a. Calculate the volumes of reactants consumed and the volume of product made.

    b. Record the ratio of N_2 to H_2 to NH_3. Reduce the ratio to the lowest whole numbers possible.

	N_2 Consumed	**H_2 Consumed**	**NH_3 Produced**	**Volume Ratio N_2:H_2:NH_3**
How many liters of each substance would be consumed or produced if the reaction occurred 6.02×10^{23} times at STP?				

16. Refer to the data table in Question 15.

    a. Can the mole ratio from a balanced chemical equation be interpreted as a ratio of volumes for gases?

    b. Use mathematical concepts to explain how your answer in part *a* is possible.

17. Explain why the ratio of volumes is NOT followed in the following reactions.

$2H_2(g)$	+	$O_2(g)$	→	$2H_2O(l)$	$NH_3(g)$	+	$HCl(g)$	→	$NH_4Cl(s)$
44.8 L		22.4 L		0.036 L	22.4 L		22.4 L		0.035 L

18. Which of the following quantities are **conserved** (total amount in reactants = total amount in products) in a chemical reaction? Find an example or counter example from this activity to support your answer for each.

    a. Molecules

    b. Moles

    c. Mass

    d. Volume

    e. Atoms of an element

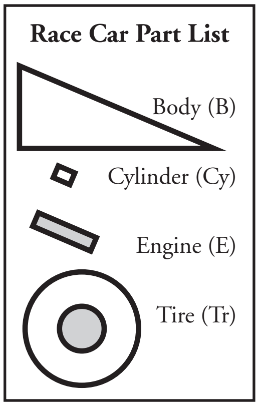
Limiting and Excess Reactants

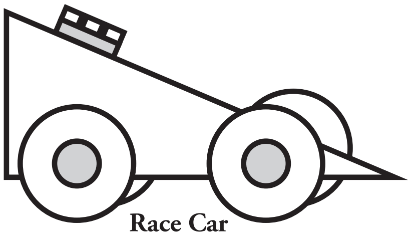
Is there enough of each chemical reactant to make a desired amount of product?

Why?

If a factory runs out of tires while manufacturing cars, production stops. No more cars can be fully built without ordering more tires. A similar thing happens in a chemical reaction. If there are fixed amounts of reactants to work with in a chemical reaction, one of the reactants may be used up first. This prevents the production of more products. In this activity, you will look at several situations where the process or reaction is stopped because one of the required components has been used up.

Model 1 – Assembling a Race Car





1. How many of each part are needed to construct 1 complete race car?

   Body (B) Cylinder (Cy) Engine (E) Tire (Tr)

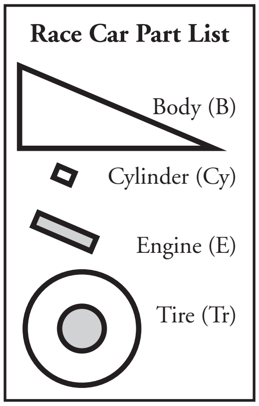
2. How many of each part would be needed to construct 3 complete race cars? Show your work.

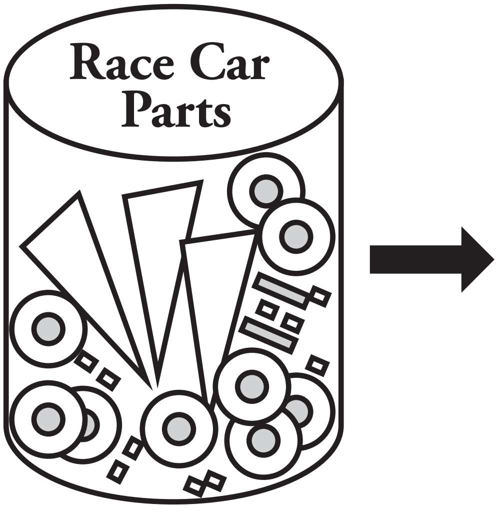
   Body (B) Cylinder (Cy) Engine (E) Tire (Tr)

3. Assuming that you have 15 cylinders and an unlimited supply of the remaining parts:
   a. How many complete race cars can you make? Show your work.

   b. How many of each remaining part would be needed to make this number of cars? Show your work.

Model 2 – Manufacturing Race Cars





Container A

4. Count the number of each Race Car Part present in Container A of Model 2.

   Body (B) Cylinder (Cy) Engine (E) Tire (Tr)

5. Complete Model 2 by drawing the maximum number of cars that can be made from the parts in Container A. Show any excess parts remaining also.
6. A student says "I can see that we have three car bodies in Container A, so we should be able to build three complete race cars." Explain why this student is incorrect in this case.
7. Suppose you have a very large number (dozens or hundreds) of tires and bodies, but you only have 5 engines and 12 cylinders.

   a. How many complete cars can you build? Show your work.

   b. Which part (engines or cylinders) limits the number of cars that you can make?

8. Fill in the table below with the maximum number of complete race cars that can be built from each container of parts (A–E), and indicate which part limits the number of cars that can be built. Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of complete cars for their container. Container A from Model 2 is already completed as an example.

1 B + 3 Cy + 4 Tr + 1 E = 1 car

Container	Bodies	Cylinders	Tires	Engines	Max. Number of Completed Cars	Limiting Part
A	3	10	9	2	2	Engines
B	50	12	50	5		
C	16	16	16	16		
D	4	9	16	6		
E	20	36	40	24		

9. The Zippy Race Car Company builds toy race cars by the thousands. They do not count individual car parts. Instead they measure their parts in “oodles” (a large number of things).

   a. Assuming the inventory in their warehouse below, how many race cars could the Zippy Race Car Company build? Show your work.

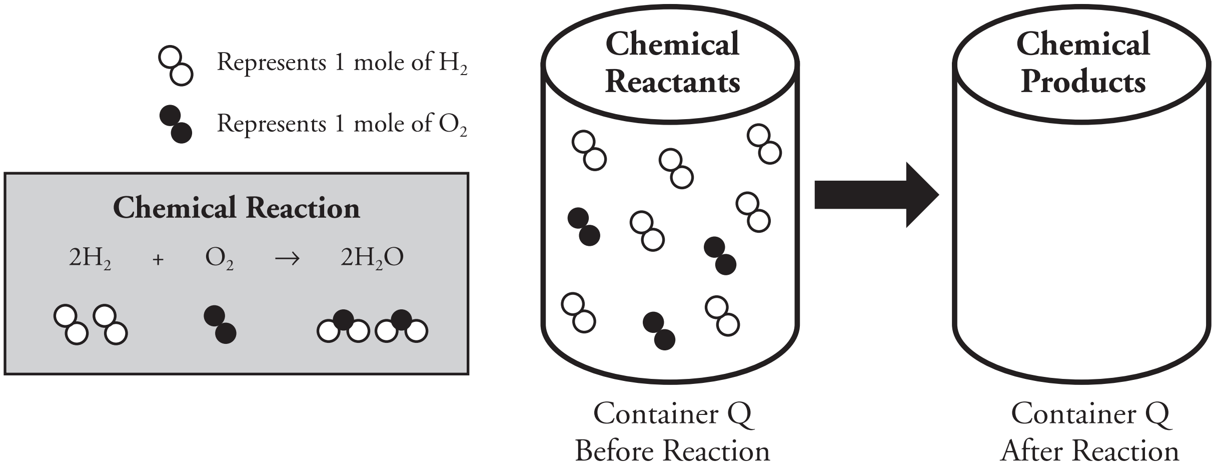
Body (B)	Cylinder (Cy)	Engine (E)	Tire (Tr)
4 oodles	5 oodles	8 oodles	8 oodles

   b. Explain why it is not necessary to know the number of parts in an “oodle” to solve the problem in part *a*.

STOP

10. Look back at the answers to Questions 8 and 9. Is the component with the smallest number of parts always the one that limits production? Explain your group’s reasoning.

Model 3 – Assembling Water Molecules


Represents 1 mole of H_2
Represents 1 mole of O_2
Chemical Reaction
$2H_2 + O_2 \rightarrow 2H_2O$
Chemical Reactants
Chemical Products
Container Q Before Reaction
Container Q After Reaction

11. Refer to the chemical reaction in Model 3.

    a. How many moles of water molecules are produced if one mole of oxygen molecules completely reacts?

    b. How many moles of hydrogen molecules are needed to react with one mole of oxygen molecules?

12. Complete Model 3 by drawing the maximum moles of water molecules that could be produced from the reactants shown, and draw any remaining moles of reactants in the container after reaction as well.

    a. Which reactant (oxygen or hydrogen) limited the production of water in Container Q?

    b. Which reactant (oxygen or hydrogen) was present in excess and remained after the production of water was complete?

13. Fill in the table below with the maximum moles of water that can be produced in each container (Q–U). Indicate which reactant limits the quantity of water produced—this is the **limiting reactant**. Also show how much of the other reactant—the **reactant in excess**—will be left over. Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of moles of water produced and the moles of reactant in excess. Container Q from Model 3 is already completed as an example.

$2H_2 + O_2 \rightarrow 2H_2O$

Container	**Moles of Hydrogen**	**Moles of Oxygen**	**Max. Moles of Water Produced**	**Limiting Reactant**	**Reactant in Excess**
Q	7	3	6	O_2	1 mole H_2
R	8	3			
S	10	5			
T	5	5			
U	8	6			

14. Look back at Questions 12 and 13. Is the reactant with the smaller number of moles always the limiting reactant? Explain your group's reasoning.

15. Below are two examples of mathematical calculations that could be performed to find the limiting reactant for Container U in Question 13.

$$8 \text{ mol } H_2 \left(\frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2}\right) = 8 \text{ mol } H_2O$$

$$6 \text{ mol } O_2 \left(\frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2}\right) = 12 \text{ mol } H_2O$$

Hydrogen makes the lesser amount of product, so it is the limiting reactant.

$$8 \text{ mol } H_2 \left(\frac{1 \text{ mol } O_2}{2 \text{ mol } H_2}\right) = 4 \text{ mol } O_2 \text{ needed}$$

There are 6 moles of O_2 present, which is more than enough, so H_2 must be the limiting reactant.

a. Do both calculations give the same answer to the problem?

b. Which method was used most by your group members in Question 13?

c. Which method seems "easier," and why?

d. Did your group use any other method(s) of solving this problem that were scientifically and mathematically correct? If so, explain the method.

Extension Questions

16. Consider the synthesis of water as shown in Model 3. A container is filled with 10.0 g of H_2 and 5.0 g of O_2.

    a. Which reactant (hydrogen or oxygen) is the limiting reactant in this case? Show your work. *Hint:* Notice that you are given reactant quantities in mass units here, not moles.

    b. What mass of water can be produced? Show your work.

    c. Which reactant is present in excess, and what mass of that reactant remains after the reaction is complete? Show your work.

Gas Variables

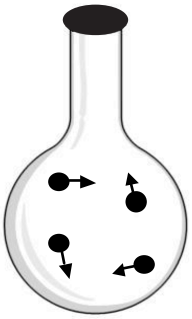
How are the variables that describe a gas related?

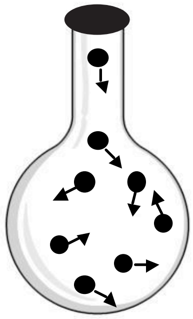
Why?

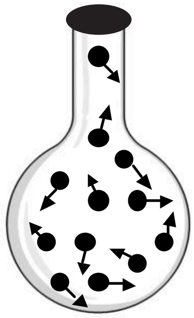
Imagine buying a balloon bouquet at a party store. How will the helium gas in the bouquet behave if you carry it outside on a hot summer day? How will it behave if you carry it outside during a snowstorm? What happens if the balloons are made of latex, which can stretch? What happens if the balloons are made of Mylar®, which cannot stretch? What if you add just a small amount of gas to each balloon? What if you add a lot of gas? In this activity, you will explore four variables that quantify gases—pressure (P), volume (V), temperature (T), and moles (n) of gas. These four variables can be related mathematically so that predictions about gas behavior can be made.

Model 1 – Gases in a Nonflexible Container

Experiment A (Adding more gas)

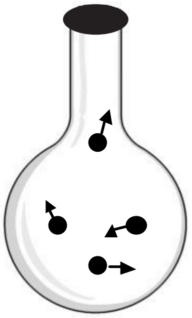


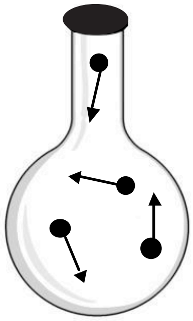


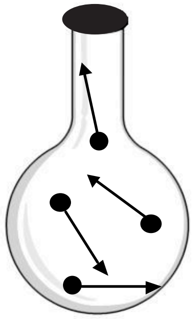


A1	A2	A3
Volume = 1 unit	Volume = 1 unit	Volume = 1 unit
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 2 atm	Internal pressure = 3 atm
Temperature = 200 K	Temperature = 200 K	Temperature = 200 K

Experiment B (Heating the gas)







B1	B2	B3
Volume = 1 unit	Volume = 1 unit	Volume = 1 unit
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 2 atm	Internal pressure = 3 atm
Temperature = 200 K	Temperature = 400 K	Temperature = 600 K

**Note:* Volume in this model is recorded in *units* rather than liters because 4 molecules of gas at the conditions given would occupy a very small space (~1×10^{-22} μL). The particles shown here are much larger compared to the space between them than actual gas particles.

1. In Model 1, what does a dot represent?

2. Name two materials that the containers in Model 1 could be made from that would ensure that they were "nonflexible?"

3. In Model 1, the length of the arrows represents the average kinetic energy of the molecules in that sample. Which gas variable ($P_{internal}$, V, T or n) is most closely related to the length of the arrows in Model 1?

4. Complete the following table for the two experiments in Model 1.

	Experiment A	**Experiment B**
Independent Variable		
Dependent Variable		
Controlled Variable(s)		

5. Of the variables that were controlled in both Experiment A and Experiment B in Model 1, one requires a nonflexible container. Name this variable, and explain why a nonflexible container is necessary. In your answer, consider the external and internal pressure data given in Model 1.

Read This!

Pressure is caused by molecules hitting the sides of a container or other objects. The pressure changes when the molecules change *how often* or *how hard* they hit. A nonflexible container is needed if the gas sample is going to have an internal pressure that is different from the external pressure. If a flexible container is used, the internal pressure and external pressure will always be the same because they are both pushing on the sides of the container equally. If either the internal or external pressure changes, the flexible container walls will adjust in size until the pressures are equal again.

6. Name the two factors related to molecular movement that influence the pressure of a gas.

7. Provide a molecular-level explanation for the increase in pressure observed among the flasks of Experiment A.

8. Provide a molecular-level explanation for the increase in pressure observed among the flasks of Experiment B.

9. Predict what would happen to the volume and internal pressure in Experiment A of Model 1 if a flexible container were used.

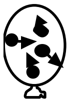
10. Predict what would happen to the volume and internal pressure in Experiment B of Model 1 if a flexible container were used.

11. For each experiment in Model 1, determine the relationship between the independent and dependent variables, and write an algebraic expression for the relationship using variables that relate to the experiment ($P_{internal}$, V, T or n). Use *k* as a proportionality constant in each equation.

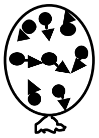
	Experiment A	**Experiment B**
Direct or Inverse Proportion?		
Algebraic Expression		

Model 2 – Gases in a Flexible Container

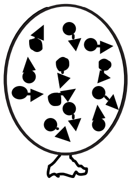
Experiment C
(Adding more gas)



C1
Volume = 1 unit
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

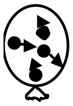


C2
Volume = 2 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

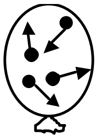


C3
Volume = 3 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

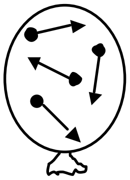
Experiment D
(Heating the gas)



D1
Volume = 1 unit
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

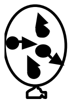


D2
Volume = 2 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 400 K

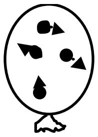


D3
Volume = 3 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 600 K

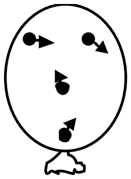
Experiment E
(Reducing the
external pressure
on the gas)



E1
Volume = 1 unit
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K



E2
Volume = 2 units
External pressure = 0.50 atm
Internal pressure = 0.50 atm
Temperature = 200 K



E3
Volume = 3 units
External pressure = 0.33 atm
Internal pressure = 0.33 atm
Temperature = 200 K

12. Consider the gas samples in Model 2.
    a. Name two materials that the containers in Model 2 could be made from that would ensure that they were "flexible"?
    b. What is always true for the external and internal pressures of a gas in a flexible container?

13. Complete the following table for the three experiments in Model 2.

	Experiment C	Experiment D	Experiment E
Independent Variable			
Dependent Variable			
Controlled Variable(s)			

14. Provide a molecular level explanation for the increase in volume among the balloons in Experiment C. (How often and/or how hard are the molecules hitting the sides of the container?)

15. Provide a molecular level explanation for the increase in volume among the balloons in Experiment D.

16. Provide a molecular level explanation for the increase in volume among the balloons in Experiment E.

STOP

17. Compare Experiment A of Model 1 with Experiment C of Model 2. How are these two experiments similar and how are they different in terms of variables?

18. Compare Experiment B of Model 1 with Experiment D of Model 2. How are these two experiments similar and how are they different in terms of variables?

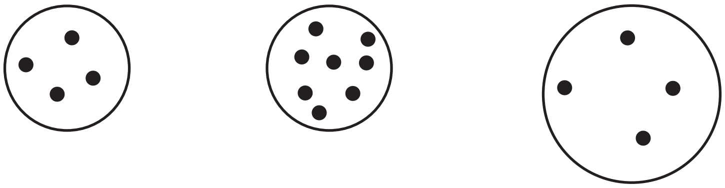
19. If Experiment E of Model 2 were done in a nonflexible container, would there be any change to the internal pressure of the flask when the external pressure was reduced? Explain.

20. For each experiment in Model 2, determine the relationship between the independent and dependent variables, and write an algebraic expression for the relationship using variables that relate to those in the experiment ($P_{internal}$, V, T or n). Use *k* as a proportionality constant in each equation.

Constant Pressure

	Experiment C	**Experiment D**	**Experiment E**
Direct or Inverse Proportion?			
Algebraic Expression			

21. The three samples of identical gas molecules below all have the same internal pressure. Rank the samples from lowest temperature to highest temperature, and add arrows of appropriate size to illustrate the average kinetic energy of the molecules in the samples.



Extension Questions

22. Draw a sample of gas that is colder than all three of the samples in Question 21. Explain why you are sure that it is colder.

23. Four of the relationships you investigated in Models 1 and 2 are named after scientists who discovered the relationships. Use the Internet or your textbook to match each of the scientists below with the appropriate law. Write the algebraic expression that describes the law in the box below each name.

Robert Boyle	Jacques Charles	Guillaume Amontons	Amedeo Avogadro

Read This!

Chemists combine all of the relationships seen in Models 1 and 2 into one law—the **Ideal Gas Law**. It is one equation that describes gas behavior and the relationship among all four variables, P, V, T, and n. In the Ideal Gas Law the proportionality constant is represented by the letter R (rather than the generic *k*).

24. Circle the algebraic equation below that best combines all of the relationships you identified among P, V, T, and n in this activity.

$P = RTnV$ $PT = RnV$ $PV = nRT$ $PTV = Rn$

Saturated and Unsaturated Solutions

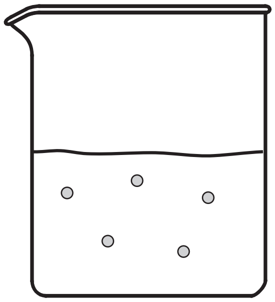
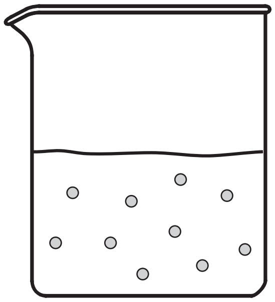
Is there a limit to the amount of solute that will dissolve in a solvent?

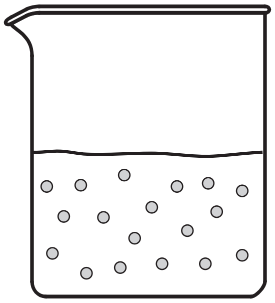
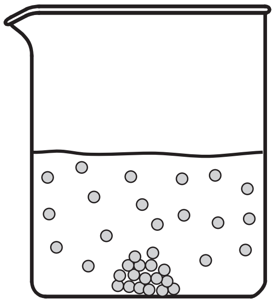
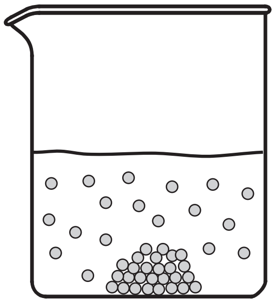
Why?

We use solutions every day. People who wear contact lenses use “lens solution” to rinse their contacts and keep them wet. Athletes who consume sports drinks after exercising benefit from the electrolytes in those solutions. This activity will explore whether or not there is a limit to how much of one substance can dissolve in another.

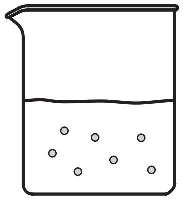
Model 1 – Saturated and Unsaturated Solutions

- All beakers contain 10.0 g of water.
- All beakers are kept at 20 °C.
- All solutions are stirred for 2 hours.
- Solute is the same substance in all beakers.

	Unsaturated Solutions	
	Beaker A	Beaker B
	 1.0 g of solute added	 2.0 g of solute added
Number of dissolved particles	5	
Number of solid particles		0

	Saturated Solutions	
Beaker C	Beaker D	Beaker E
 3.6 g of solute added	 7.0 g of solute added	 9.0 g of solute added
		18
	17	

1. Which illustration below represents
   a. solute particles in a solid state in water?
   b. solute particles in an aqueous state?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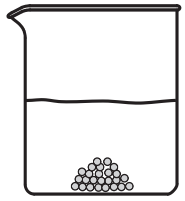

____

2. What variables are controlled in all five beakers of Model 1?

3. Count the particles present in each beaker of Model 1. Fill in the table to show the number of dissolved solute particles and the number of solid solute particles.

4. Consider the beakers in Model 1.
   a. Which beakers represent **unsaturated** solutions?

   b. Which beakers represent **saturated** solutions?

5. Beakers A–E in Model 1 are depicted as representing five different or separate solutions. They could also be considered as five "snapshots" of the same beaker over time. In other words, if additional measured quantities of solute were stirred into beaker A in small increments over time, then beakers B–E would result.
   a. When a small amount of additional solute is added to an unsaturated solution, what happens to the number of dissolved particles? Provide specific evidence from Model 1 to support your answer.

   b. When a small amount of additional solute is added to a saturated solution, what happens to the number of dissolved particles? Provide specific evidence from Model 1 to support your answer.

   c. Predict what would happen if a small amount of additional solute were stirred into beaker E in Model 1.

STOP

6. Have each person in your group provide an example of the word “saturated” as it is used in an everyday context. Summarize the meaning of the word in the space below.

7. Use a grammatically correct sentence to explain why beakers D and E in Model 1 are labeled as “saturated.” Be sure to incorporate the words “solute” and “solvent” in your explanation, and reach a consensus within your group.

8. What feature in the beakers in Model 1 would typically enable a student to distinguish a saturated solution from an unsaturated one simply by looking at the beaker?

9. Beaker C in Model 1 is shown as “saturated.” Explain why this is the correct category for beaker C even though the typical feature listed in Question 8 is not present.

10. If you were handed a beaker containing a clear solution (with no solid solute at the bottom), and asked to identify it as “saturated” or “unsaturated,” what simple test could you perform to determine the answer.

STOP

Model 2 – Solute Dissolved vs. Solute Added

The following data refer to an experiment in which a measured mass of solid is added to 10.0 g of 20 °C water. The mixture is stirred and allowed to sit for 3 hours. Ten separate trials are conducted for the experiment.

Trial Number	Mass of solute added (grams)	Mass of solute dissolved (grams)
1	1.0	1.0
2	2.0	2.0
3	3.0	3.0
4	4.0	3.6
5	5.0	3.6
6	6.0	3.6
7	7.0	3.6
8	8.0	3.6
9	9.0	3.6
10	10.0	3.6

11. Four of the trials in Model 2 correspond to beakers A, B, D, and E from Model 1. Write the letters for those beakers next to the corresponding trial numbers in Model 2.
12. Identify the following variables in the experiment in Model 2.

    Dependent variable   Independent variable   Controlled variable(s)

13. Sketch a graph of the data for the experiment in Model 2. A space has been provided next to the data table. Be sure to consider which variable belongs on each axis.
14. Consider the data in Model 2.
    a. Which trials represent solutions that are unsaturated?

    b. Which trial numbers represent solutions that are saturated?

    c. Describe the feature in the graph that can help you identify the saturated solutions. Explain.

STOP

15. Which trials in the experiment in Model 2 would have visible amounts of solid on the bottom of the beaker?

16. For Trial 8 in Model 2, determine the mass of solid solute remaining on the bottom of the beaker. Show your calculation.

17. Imagine that the contents of the beaker for Trial 8 in Model 2 are vigorously stirred and then poured into filter paper in a funnel.

    a. Is the liquid that drips from the filter (the filtrate) unsaturated or saturated? Explain.

    b. Which beaker in Model 1 best represents the filtrate that would be obtained?

Extension Questions

18. Predict what would happen to the mass of solid solute sitting on the bottom of the beaker in Trial 8 in Model 2 when the following changes occur. Use complete sentences to support your predictions.

    a. More water is added to the beaker.

    b. The beaker is heated (assume no evaporation occurs).

    c. The beaker is allowed to sit uncovered for two days and some water evaporates.

Solubility

How is the quantity of solute in a saturated solution determined?

Why?

When we add salt to a pot of boiling water or sugar to a pitcher of iced tea, we expect that the added solute will completely dissolve. It requires a large quantity of these solutes to saturate a solution. On the other hand, water has flowed over rock riverbeds for centuries and only dissolved enough material in some cases to provide a trace of certain minerals in the water. Different solutes, such as salt, sugar, or minerals, dissolve to very different extents in water (and other solvents). In this activity you will learn how to quantify the amount of solute that is dissolved in a saturated solution.

Model 1 – Three Solutions

The following data refer to three experiments in which solute is added to water in a beaker at 20 °C. The mixtures are stirred and then allowed to sit for three hours before measuring the amount of solid that dissolves. Ten separate trials are conducted for each experiment. The same solute is used in all three experiments.

	Experiment 1 In 10.0 g water		**Experiment 2 In 20.0 g water**		**Experiment 3 In 50.0 g water**	
Trial	Mass of solute added (grams)	Mass of solute dissolved (grams)	Mass of solute added (grams)	Mass of solute dissolved (grams)	Mass of solute added (grams)	Mass of solute dissolved (grams)
1	1.0	1.0	1.0	1.0	3.0	3.0
2	2.0	2.0	2.0	2.0	6.0	6.0
3	3.0	3.0	3.0	3.0	9.0	9.0
4	4.0	3.6	4.0	4.0	12.0	12.0
5	5.0	3.6	5.0	5.0	15.0	15.0
6	6.0	3.6	6.0	6.0	18.0	18.0
7	7.0	3.6	7.0	7.0	21.0	18.0
8	8.0	3.6	8.0	7.2	24.0	18.0
9	9.0	3.6	9.0	7.2	27.0	18.0
10	10.0	3.6	10.0	7.2	30.0	18.0

1. Identify the variable(s) that were controlled among all three experiments in Model 1.

2. What variable(s) were changed purposefully among the three experiments in Model 1?

3. What experimental question can be answered by analyzing the data in the three experiments in Model 1? Use the words "solvent" and "solute" in your question.

4. In each of the three experiments in Model 1, determine the point in the experiment that the beakers became saturated. Draw a box around the entire section of data in each experiment that represents saturated solutions.

5. Consider the data in Model 1.
   a. Which experiment shows the largest mass of dissolved solute in the saturated solutions?

   b. Propose an explanation for why the mass of dissolved solute changed among the three experiments.

Read This!

Solubility is a measure of the maximum amount of solute that can dissolve in a given amount of solvent at a specific temperature. In other words, it is the ratio of solute to solvent in a saturated solution at a specific temperature. Solubility is typically reported as grams of solute per 100 g H_2O. For example, if a maximum of 20.4 g of table sugar (sucrose) will dissolve in 10.0 g of water at 20 °C, then the solubility of sucrose would be 204 g sucrose/100 g H_2O.

6. Would it be acceptable for a student to use Trial 2 from Experiment 1 to determine the solubility of the solute in Model 1? Explain your group's answer in a complete sentence.

7. In Model 1 none of the experiments used 100 g of water. Use complete sentences to explain how the ratio "grams of solute per 100 g H_2O" can be calculated from the data given in Model 1.

8. Use the data in Model 1 to calculate the solubility of the solute (at 20 °C) for all three experiments. Show your work.

   Experiment 1: Experiment 2: Experiment 3:

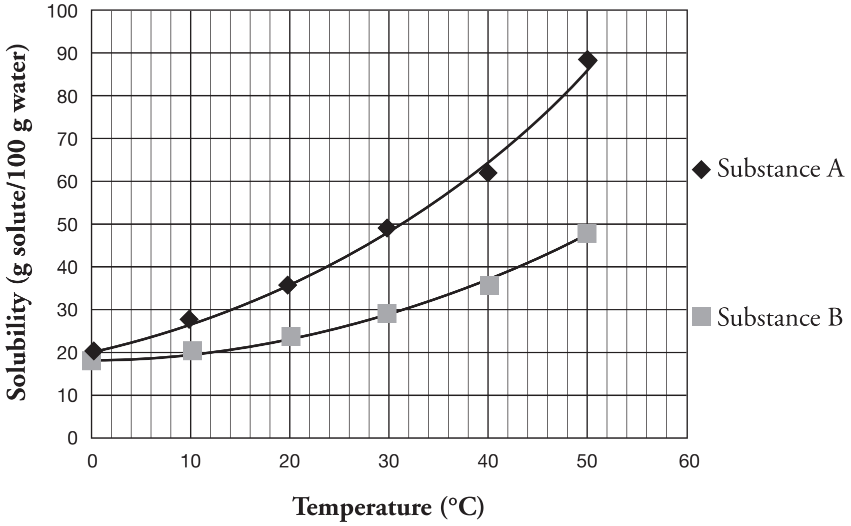
9. Circle the word or phrase that best completes each of the statements below.
   a. When the volume of solvent increases, the mass of solute that can dissolve in a saturated solution (increases/decreases/stays the same).
   b. When the volume of solvent increases, the solubility of a solute at a given temperature (increases/decreases/stays the same).

10. A student claims, "In Experiment 3, Trial 9, 18.0 grams of solute dissolves, whereas in Experiment 1, Trial 9, only 3.6 grams of solute dissolves. Obviously, the solubility is greater in Experiment 3." With your group, devise a well-constructed response.

11. Calculate the mass of the solute used in Model 1 that is needed to make a saturated solution in 140.0 g of water without leaving any solid solute at the bottom. Show your work.

Extension Questions

Model 2 – Solubility Curves



12. According to the graph in Model 2, what is the solubility of Substance A at 30 °C?

13. Describe the trend in solubility for Substances A and B in Model 2 as temperature increases.

14. If a saturated solution of Substance A in 100.0 g of water is cooled from 30 °C to 10 °C, what mass of solid solute would crystallize out? Show your work.

15. If a saturated solution of Substance B in 50.0 g of water at 30 °C is warmed to 50 °C, what mass of solute would need to be added to make the solution saturated again?

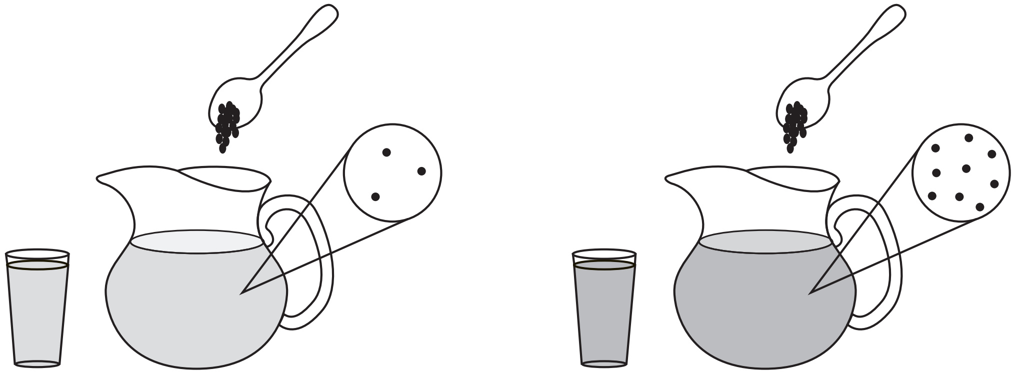
Molarity

How can the concentration of a solution be expressed quantitatively?

Why?

When you buy a bottle of a certain brand of lemonade you expect it to taste just as sweet as the last time you bought that kind of lemonade. Likewise, when doctors prescribe a certain ointment, they expect the concentration of medicine to be consistent. How do companies ensure their products taste or perform the same every time you purchase them? Many companies, including pharmaceutical companies, keep track of the concentration of a solution by measuring its **molarity**—a ratio of number of solute particles to the volume of solution. In this activity you will learn about molarity and how to represent concentration quantitatively.

Model 1 – Lemonade Mixtures*



Lemonade Solution 1

Lemonade Solution 2

* Both pitchers were filled with enough water (solvent) to provide 2 liters of solution.

Dissolved Lemonade Mix particle (solute) = •

1. Refer to Model 1.
   a. What is the solvent in this scenario?
   b. What is the solute in this scenario?
   c. What is a dissolved lemonade mix particle represented by?
2. Circle the word that best completes each sentence below and justify your answer based on the diagrams in Model 1.
   a. Lemonade Solution 1 has (more/less/the same) volume of solution as 2. How do you know?

   b. Lemonade Solution 1 has (more/less/the same) quantity of solute as Solution 2. Describe how you know in terms of number of particles.

3. Lemonade Solution 2 is considered to be **concentrated**, and lemonade Solution 1 is considered to be **dilute**. Examine the two pictures in Model 1. List two ways to differentiate a concentrated solution from a dilute solution.

4. A glass is filled with the concentrated lemonade solution from Model 1.

   a. Is the solution in the glass the same concentration as the solution in the pitcher?

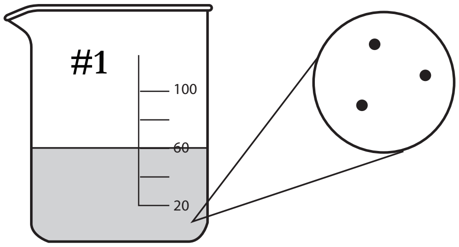
   b. Does the solution in the glass contain the same number of solute particles as the solution in the pitcher? If no, explain how your answer to part *a* can be true. *Hint:* Consider both amount of solute and amount of solvent.

5. Do the terms "concentrated" and "dilute" provide any specific information about the quantities of solute or solvent in a solution? Explain.

Model 2 – Chemical Solutions

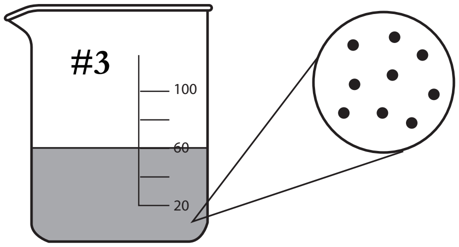
Dilute

Concentrated



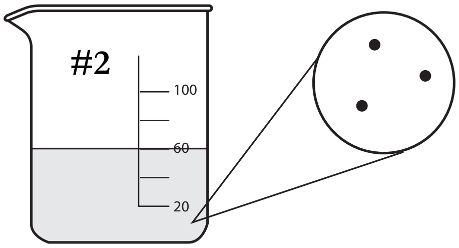
1 M $CuCl_2$ Solution

0.06 mole $CuCl_2$ in 0.06 L solution



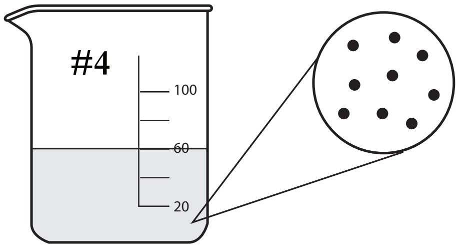
3 M $CuCl_2$ Solution

0.18 mole $CuCl_2$ in 0.06 L solution



1 M Glucose Solution

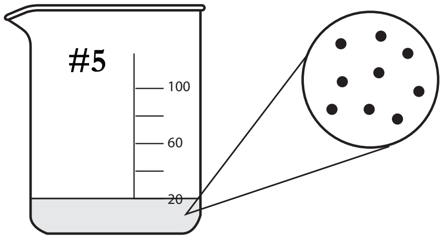
0.06 mole glucose in 0.06 L solution



3 M Glucose Solution

0.18 mole glucose in 0.06 L solution

M = Molarity
"3 M" is read as "three molar"



3 M Glucose Solution

0.06 mole glucose in 0.02 L solution

6. List the beaker numbers for the solutions in Model 2 that are considered to be “concentrated.”

7. What does the letter “M” stand for in Model 2?

8. Use the data in Model 2 to answer the questions below.

   a. Calculate the ratio of the moles of solute to liters of solution for each solution.

   $$\frac{\text{moles of solute}}{\text{liters of solution}}$$

   b. How does the ratio compare to the molarity of each solution?

9. Write a mathematical equation to show how the molarity of a solution is calculated.

10. Which type of solution (dilute or concentrated) will have a larger molarity value?

11. Consider beakers 3–5 in Model 2. Circle the answer below for the quantity that is the same in all of the beakers that contain 3 M solutions.

    Number of moles of solute

    Volume of solution

    Ratio of moles of solute to liters of solution

12. Explain how beaker 5, with fewer moles of glucose, can have the same molarity as beaker 4.

13. Can molarity be determined by knowing either the number of moles alone or the volume of solution alone? Explain why or why not.

14. Calculate the molarity of a solution containing 1.5 moles of NaCl in 0.50 liters of solution. Show your work.

15. Calculate the molarity of a solution containing 0.40 moles of acetic acid in 0.250 liters of solution. Show your work.

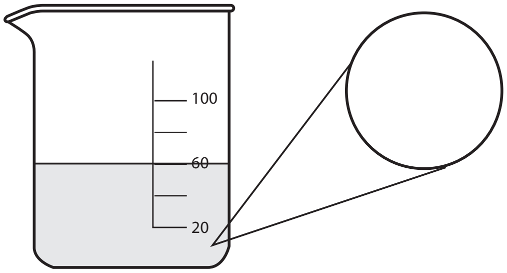
16. A 0.5 M KCl solution contains 74.55 g of KCl (molar mass 74.55 g/mol) in 2000 mL of solution.

   a. Does the ratio 74.55 g KCl/2000 ml provide the correct molarity for this solution?

   b. What units do the amount of solute and the volume of solution need to be in to obtain the molarity of 0.5 M? Show the calculation.

17. Calculate the molarity of a solution containing 2.5 g of $CuCl_2$ in 1 L of solution. Show your work, including units.

18. Consider the 3 M solutions in Model 2. What would a 3 M HCl picture look like if the beaker contained 100 mL? In the circle below, visually show the number of solute particles that would be present in any very small volume of the overall solution. (See Model 2 for examples.)



Extension Questions

19. A student thinks that she can determine the concentration of a solution based on the darkness or color intensity of the solution alone. Based on the pictures in Model 2 describe why this student's method will not always work.

20. Calculate the molarity of a KCl solution if 37.3 g of KCl are dissolved in water to give a final solution volume of 500 mL. Show your work.

21. A student correctly determines that 17.1 grams of sucrose are needed to make 50 mL of a 1 M sucrose solution. When making this solution in lab, the student measured 50 mL of water and massed 17.1 grams of sucrose. The student then mixed the two together into a new beaker. The student's resulting solution was not 1 M sucrose as intended. After the student mixed sucrose and water, the resulting solution was poured into a graduated cylinder and it read 62 mL.

    a. What part of the molarity equation did the student overlook when mixing the solution?

    b. What steps should the student take in lab to correctly prepare the 1 M solution?

Calorimetry

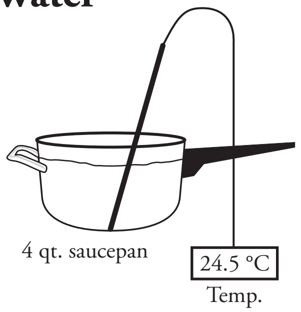
What is the relationship between heat energy and temperature?

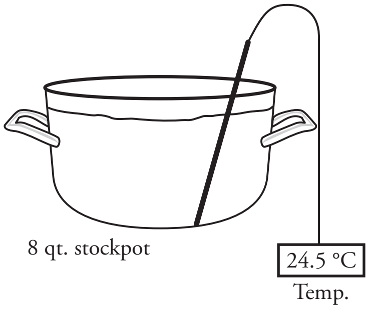
Why?

When a substance is heated, the temperature of that substance increases. Will the same amount of energy cause different substances to have identical temperature increases? Will the same amount of energy be needed to cause identical temperature increases in different amounts of the same substance? In this activity you will explore how mass, temperature, heat energy, and the type of substance are related.

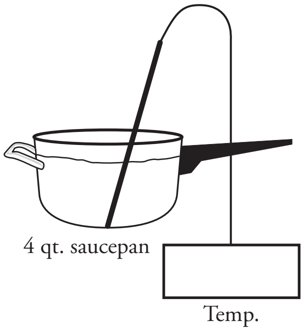
Model 1 – A Pot of Water

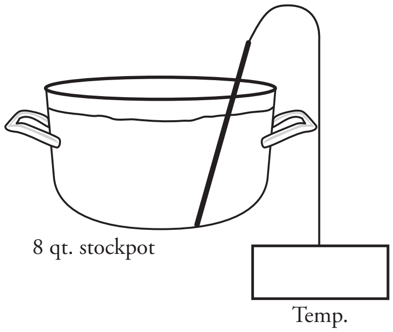
Before heating





After heating for 5 minutes at a rate of 30 Joules per minute





1. In Model 1, which container holds more grams of water?

2. Consider the process described in Model 1:
   a. How many joules of energy were added to the saucepan?

   b. How many joules of energy were added to the stockpot?

   c. In which container did the liquid gain more energy or did both gain the same amount? Explain your reasoning.

   d. For each container, include whether the temperature is expected to increase, decrease or remain the same after heating. Explain your reasoning.

Model 2 – Experimental Data for Heating Water

Experiment 1

Trial	Mass (g)	ΔT (°C)	Added Energy (Joules)
A	1.00	26.8	112
B	2.00	13.4	112
C	2.50	10.7	112
D	3.00	8.93	112
E	3.50	7.66	112
F	4.00		112

Experiment 2

Trial	Mass (g)	ΔT (°C)	Added Energy (Joules)
A	3.00	3.00	37.6
B	3.00	6.00	75.2
C	3.00	9.00	113
D	3.00	12.0	150
E	3.00	15.0	188
F	3.00	18.0	

Experiment 3

Trial	Mass (g)	ΔT (°C)	Added Energy (Joules)
A	1.00	9.00	37.6
B	2.00	9.00	75.0
C	2.50	9.00	94.1
D	3.00	9.00	113
E	3.50	9.00	132
F	4.00		150

3. In the data tables in Model 2, what does ΔT mean?

4. Which experiment in Model 2 illustrates how the amount of energy needed to achieve the same temperature change depends on the mass of water?

5. Which experiment in Model 2 illustrates how different amounts of energy result in different temperature changes when the mass of water is constant?

6. Why was it necessary to perform three experiments to find the relationships between mass, temperature change, and energy?

7. Refer to Experiment 1 in Model 2, and consider the relationship between the mass of water and the observed temperature change when the same amount of energy is added.

   a. Complete the statement below to show the relationship.

   When the same amount of energy is added to water samples of different mass, the change in temperature gets (smaller/larger) as the mass of the water increases.

   b. Does the relationship stated in part *a* describe a direct or inverse relationship?

8. Refer to Experiment 2 in Model 2.

   a. Write a grammatically correct sentence (like the one in Question 7*a*) to describe the relationship between the observed temperature change and the energy required to heat water samples of identical mass.

   b. Does the relationship stated in part *a* describe a direct or inverse relationship?

9. In Experiment 2, should the value of the missing energy in the last row be larger or smaller than the other energy values in that column?

10. Refer to Experiment 3 in Model 2.

    a. Write a grammatically correct sentence to describe the relationship between the mass of water and the energy required to produce the same temperature change in different water samples.

    b. Does the relationship stated in part *a* describe a direct or inverse relationship?

11. Each of the experiments in Model 2 can be expressed as a proportionality indicated by the following symbol: $\propto$. Several possible equations are shown in the table below.

$q \propto m$	$q \propto 1/m$
$q \propto \Delta T$	$q \propto 1/\Delta T$
$\Delta T \propto m$	$\Delta T \propto 1/m$

    a. Describe what each variable represents in the equations shown above?

    m = ΔT = q =

    b. For each experiment in Model 2, indicate which of the six proportionalities shown in the table above correctly describes the relationship observed by the results of that experiment.

    Experiment 1   Experiment 2   Experiment 3

STOP

12. Based on your answers in Question 11, write a single proportionality statement that includes all three variables: q, m, ΔT. The statement should use q as the variable on the left.

13. A proportionality statement can become an equation when a constant is determined. The equation will have q on the left side of the equal sign and a constant “c” on the right side of the equation. Re-write the proportionality statement from Question 12 as an equation using “c” for the constant. After reaching consensus on this equation in your group, compare your answer with other groups to verify your equation.

14. Solve for the value of the constant “c” using data from Model 2. Your teacher may assign you a specific experiment to use. Your group should calculate the value of c by using one set of data from each of the three experiments (include the units of this constant). After you complete the three calculations, compare your value for the constant with the value that other groups determined.

15. The constant obtained in Question 14 is called the **specific heat**, (c). It is an intensive physical property that has a different, characteristic value for every substance. What is the value for the specific heat of water?

16. What do the units for specific heat mean? (Make sure your answer is a grammatically correct sentence.)

17. Using your equation for energy transferred (q) from Question 13 and the calculated value for the specific heat of water, determine the amount of energy required to increase the temperature of 550 grams of water by 20.0 °C.

18. Using your equation for transferred energy (q) and the specific heat, determine the values for the missing data in the three experiments in Model 2. (Trial F in experiments 1–3.)

19. Use your equation from Question 13 to calculate the following:
    a. How much energy is transferred when 30.0 g of water is cooled from 25.0 °C to 12.7 °C.

    b. Describe the significant difference between this value and the energy values shown in Model 2.

Extension Questions

Model 3 – Heating Mercury and Water

Trial	Substance	Mass (grams)	ΔT (°C)	Added Energy (Joules)
1	Hg	100.0	71.0	1,000.0
2	Hg	100.0	142	2,000.0
3	H_2O	100.0	2.39	1,000.0
4	H_2O	100.0	4.78	2,000.0

20. What two substances are being heated in the experiments described in Model 3?

21. Compare any two trials in Model 3 that use the same amount of energy but involve different substances. Is the temperature change the same or different in the two trials?

22. Based on the data in this activity, the specific heat of water was determined to be 4.18 J/ g•°C. Use data from Model 3 to solve for the value of the specific heat for mercury.

23. Select the correct word to complete the sentence:

    When adding the same amount of energy to two similar massed samples, the substance with the larger specific heat will have a (larger or smaller) temperature change?

24. If 23,000 joules of energy are used to heat water by 4.00 °C, what is the mass of the water?

25. If 23,000 joules of energy are used to heat mercury by 4.00 °C, what is the mass of the mercury?

26. What is the specific heat of aluminum if 4,750 joules of heat energy added to 249 g of aluminum produces a recorded temperature change of 21.1 °C?

Bond Energy

What makes a reaction endothermic or exothermic?

Why?

Chemical reactions can be a lot like playing with Legos®—you must take apart part of your last creation before you can replace it with something new. For many chemical reactions, we have to first break bonds in the reactants before we can put the atoms back into a new arrangement to form the products. Both of these processes involve changes in energy. The net energy change for a reaction is called the **heat of reaction** or the **change in enthalpy** (ΔH). In this activity we will look at one way energy changes can be approximated for chemical reactions.

Model 1 – Breaking and Forming Bonds

	Reaction	**Change in Energy (kJ/mol_{rxn})**
A)	$PCl_3(g) \rightarrow P(g) + 3Cl(g)$	+ 966.7
B)	$PCl_5(g) \rightarrow P(g) + 5Cl(g)$	+ 1,297.9
C)	$PF_3(g) \rightarrow P(g) + 3F(g)$	+ 1,470.4
D)	$PF_5(g) \rightarrow P(g) + 5F(g)$	+ 2,305.4

	Reaction	**Change in Energy (kJ/mol_{rxn})**
E)	$P(g) + 3Cl(g) \rightarrow PCl_3(g)$	– 966.7
F)	$P(g) + 5Cl(g) \rightarrow PCl_5(g)$	– 1,297.9
G)	$P(g) + 3F(g) \rightarrow PF_3(g)$	– 1,470.4
H)	$P(g) + 5F(g) \rightarrow PF_5(g)$	– 2,305.4

1. Identify four reactions in Model 1 where bonds are being broken. Write "broken" in the Change in Energy box in the table for each reaction you identify.
2. Identify four reactions in Model 1 where bonds are being formed. Write "formed" in the Change in Energy box in the table for each reaction you identify.
3. Circle the correct word to complete each sentence below.
   a. When bonds are (broken/formed) there is a positive energy change.
   b. Breaking bonds is (endothermic/exothermic).
   c. When bonds are (broken/formed) there is a negative energy change.
   d. Forming bonds is (endothermic/exothermic).
4. Find two reactions in Model 1 that are exact opposites of each other, that is, one reaction is the reverse of the other reaction.
   a. How do the changes in energy for the reverse reactions compare?
   b. Explain your answer to part *a* considering what you learned from Questions 1–3 about bond breaking and bond formation.

5. Consider the data in Model 1.
   a. What unit is on the energy changes?

   b. For Reaction A of Model 1, how many P–Cl bonds are broken with the 966.7 kJ of energy listed? *Hint:* Look at the units you listed in part *a*.

   c. Calculate the energy needed to break one mole of P–Cl bonds in Reaction A.

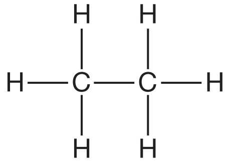
6. Use the data in Model 1 to answer the following questions.
   a. Calculate the energy needed to break one mole of P–Cl bonds in Reaction B.

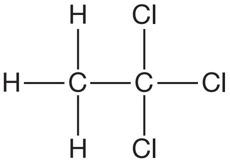
   b. Do the P–Cl bonds in different molecules require the same amount of energy to break?

STOP

Read This!

The energies you calculated in Questions 5*c* and 6*a* above are called **bond energies**. The bond energy for a particular type of bond can vary from one molecule to another because the atomic environment of a bond can influence the amount of energy needed to break the bond. For example the carbon–carbon bond in the two molecules shown below may not have the same bond energy because the surrounding atoms are different.





Bond energies can be very useful (as you will soon discover) for calculating the net energy change in a reaction. However, a table listing the bond energies for even the most common substances would be several pages long. For this reason, chemists often approximate energy changes using *average* bond energy.

Model 2 – Average Bond Energy

Bond	Energy (kJ/mol)	Bond	Energy (kJ/mol)
H—H	432	N—N	160
C—H	411	N═O	631
N—H	386	N≡N	941
H—Cl	431	N—O	201
C—C	346	Cl—Cl	243
C—O	358	F—F	158
C—N	305	O—H	464
C—Cl	327	O—Cl	269
C═C	602	O—O	204
C═O	745	C—F	552
O═O	494	C—S	259

7. Look at the bond energies in Model 2.
   a. Are the bond energies positive or negative?

   b. Do the bond energies refer to bond-breaking or bond-forming processes?

8. Look at the energy values in Model 2.
   a. What are the units for bond energy?

   b. How many bonds will the energy listed in the table break or form?

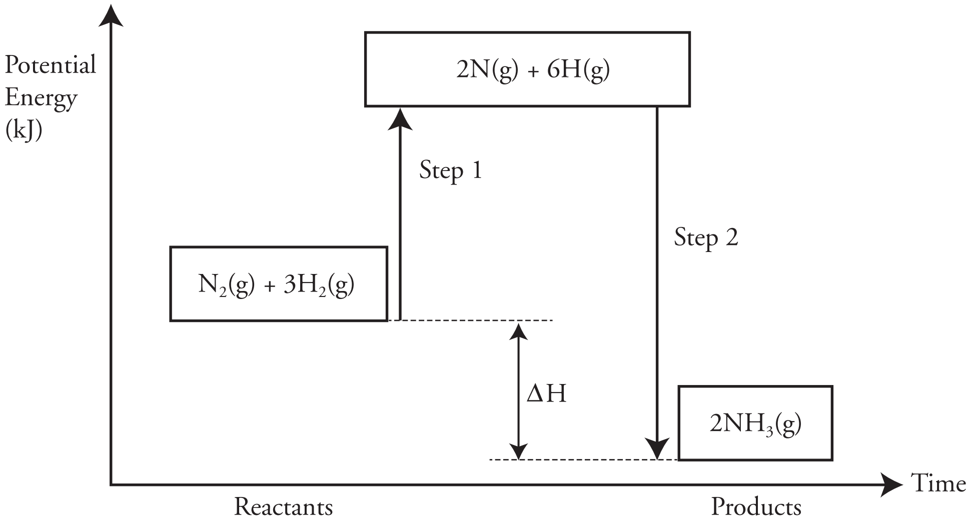
9. Is the bond energy for a double bond simply two times that of a single bond for the same atoms? Provide two specific examples to support your answer.

10. Explain how to use the information in Model 2 to determine the change in energy when a mole of C—H bonds is *formed* rather then broken.

11. Because the environment surrounding a bond in a molecule alters the bond energy slightly, predict how scientists might calculate *one* bond energy value for the table in Model 2.

STOP

Model 3 – Calculating the Net Energy Change of a Reaction



12. Write the overall reaction for the process that is illustrated in Model 3.

13. What does the *y*-axis on the graph in Model 3 represent?

14. Consider the process illustrated in Model 3.
    a. Does Step 1 represent a bond-breaking or bond-forming process?
    b. Explain why the Step 1 arrow goes up—toward higher potential energy—rather than down.

15. Draw a Lewis dot diagram for *every* reactant molecule in Model 3.

16. Use the bond energies in Model 2 to calculate the energy needed to break apart the four moles of molecules in Step 1 of the reaction in Model 3. Include the proper sign and units on your answer.

17. Draw a Lewis dot diagram for *every* product molecule in Model 3.

18. Use the bond energies in Model 2 to calculate the energy that is released to form the two moles of molecules in Step 2 of the reaction in Model 3. Include the proper sign and units on your answer.

19. The heat of reaction or change in enthalpy (ΔH) of a reaction is the net energy change in the reaction. Consider where ΔH is located in Model 3. Discuss with your group members how your answers to Questions 16 and 18 could be used to calculate the enthalpy change (ΔH) for the reaction in Model 3, and then do the calculation.

Read This!

The diagram in Model 3 suggests that the production of ammonia from its elements occurs by breaking the element molecules into single gaseous atoms and then recombining them into ammonia. In actuality, very few chemical reactions occur in this manner. In fact, the production of ammonia does not happen this way. Lucky for chemists, it doesn't really matter. Enthalpy is a state function, which means the actual process or pathway by which the reaction takes place does not affect the net energy change. Therefore, it is perfectly alright to *imagine* that the reaction occurs as illustrated in Model 3. The enthalpy change that is calculated will still approximate the real-life reaction because for a state function like enthalpy only the beginning state (reactants) and the ending state (products) must be known.

20. Balance the following reaction.

$CH_4 + O_2 \rightarrow CO_2 + H_2O$

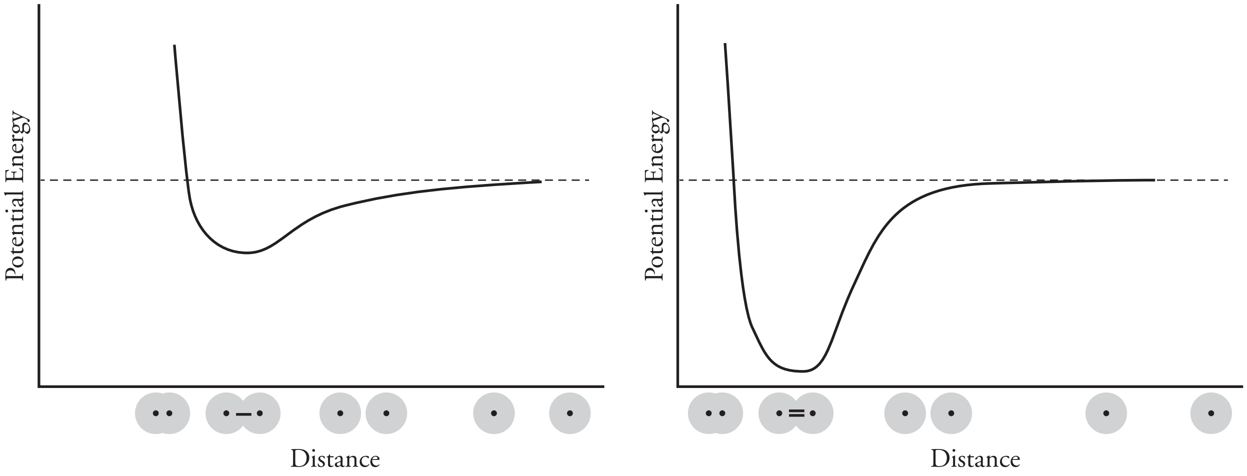
21. Draw a Lewis dot diagram for *every* reactant and product molecule in the reaction in Question 20.

22. Use the average bond energy in Model 2 to calculate the change in enthalpy (ΔH) for the reaction in Question 20.

23. Why are the changes in enthalpy calculated using average bond energies considered approximate values?

Extension Questions

Model 4 – C—C Bond versus C═C Bond



24. The graphs in Model 4 show the change in potential energy as a function of the distance between two atoms as they approach each other to form a bond. What two bonds do the graphs represent?

25. Consider the information in Model 4.
    a. What happens to the potential energy of the atoms as they get closer to each other and form a bond?

    b. Explain your answer in part *a*. Your answer should include a discussion of attractive and repulsive forces.

    c. Does this difference in potential energy cause a release of energy or absorption of energy from the atoms?

26. Consider the information in Model 4.
    a. What happens to the potential energy of the atoms if they get too close to each other?

    b. Explain your answer in part *a*. Your answer should include a discussion of attractive and repulsive forces.

27. Compare the two graphs in Model 4.

   a. Which bond in Model 4 (the single bond or double bond) will release a larger amount of potential energy when it forms?

   b. Which bond in Model 4 (the single bond or double bond) will have a larger average bond enthalpy value?

   c. Which bond in Model 4 (the single bond or double bond) has a shorter bond length?

   d. Explain how the graphs in Model 4 help you answer the question in part *c*.

Equilibrium

At what point is a reversible reaction "completed"?

Why?

Most of the reactions that we have studied this year have been "forward" reactions—once the reactant has changed into the product it stays that way. We can assume that eventually the reaction will "finish" when the limiting reactant runs out. However, in a reversible reaction (one that can take place in both directions), once the product is formed it can turn back into the reactant and a continuous cycle occurs. When do reactions such as these "finish?" Is there ever an end, and can we predict how much reactant or product will be present when the reaction is "done?"

Model 1 – A Reversible Reaction

$$\mathbf{A(g) \rightleftarrows B(g)}$$

1. What is the reactant in the reaction in Model 1?

2. What is the product in the reaction in Model 1?

3. What is the significance of the double arrow in the equation in Model 1?

4. Imagine that the reaction in Model 1 starts with 100 molecules of A and zero molecules of B. Explain why the concentration of substance A will never reach zero.

5. Imagine the reaction in Model 1 starts with zero molecules of A and 100 molecules of B. Will the concentration of substance B increase or decrease as the reaction proceeds? Explain.

6. Consider an initial concentration of 5.00 moles of A and zero moles of B for the reaction in Model 1. If 60% of the available A molecules react each minute, calculate the concentration of A and B after one minute. Fill in the table below with your answers. Be prepared to discuss your method of calculation with the class.

	A		B	
Initial Starting moles of A	5.00 moles		0.00 moles	**Initial** Starting moles of B
Change Forward Moles of A reacted	–	⟶	+	**Change Forward** Moles of B made
End Moles of A after 1 minute	=		=	**End** Moles of B after 1 minute

7. Did you use the mole ratio between substance A and substance B in Question 6? If not, make a correction.

8. Consider an initial concentration of 5.00 moles of A and 2.00 moles of B for the reaction in Model 1. If 60% of the available A molecules react each minute, and 20% of the available B molecules also react each minute, calculate the concentrations of A and B after one minute. Fill in the table below with your answers. *Hint:* Since the forward and reverse reactions happen simultaneously, calculate the "change reverse" based on the initial 2.00 moles of B.

	A		B	
Initial Starting moles of A	5.00 moles		2.00 moles	**Initial** Starting moles of B
Change Forward Moles of A reacted	–	⟶	+	**Change Forward** Moles of B made
Change Reverse Moles of A made	+	⟵	–	**Change Reverse** Moles of B reacted
End Moles of A after 1 minute	=		=	**End** Moles of B after 1 minute

STOP

9. Obtain a set of starting conditions from the instructor. Enter the initial moles of A and B in Model 2 as well as the percent of A molecules that react each minute (over the first forward arrow) and the percent of B molecules that react each minute (over the first reverse arrow).

Model 2 – Reaching Equilibrium

		A		B
1 minute	**Initial**			
	Change Forward	–	→	+
	Change Reverse	+	←	–
	End	=		=
2 minutes	**Change Forward**	–	→	+
	Change Reverse	+	←	–
	End	=		=
3 minutes	**Change Forward**	–	→	+
	Change Reverse	+	←	–
	End	=		=
4 minutes	**Change Forward**	–	→	+
	Change Reverse	+	←	–
	End	=		=
5 minutes	**Change Forward**	–	→	+
	Change Reverse	+	←	–
	End	=		=
6 minutes	**Change Forward**	–	→	+
	Change Reverse	+	←	–
	End	=		=
7 minutes	**Change Forward**	–	→	+
	Change Reverse	+	←	–
	End	=		=
8 minutes	**Change Forward**	–	→	+
	Change Reverse	+	←	–
	End	=		=
9 minutes	**Change Forward**	–	→	+
	Change Reverse	+	←	–
	End	=		=

10. Complete the calculations required for Model 2. Round your answers to the nearest hundredth of a mole. Take turns doing the calculations and check each other's work.

Read This!

Reversible reactions never come to an end: they just reach **equilibrium**. That is, they reach a point where there is no further change in concentration of any species in the reaction. The forward and reverse reactions continue to happen, but the moles of any species in the reaction that are produced or used in a specific time period are the same, so the overall quantities of all the reactants and products remain constant.

11. Identify the time in Model 2 at which your reaction reached equilibrium.

12. When equilibrium was reached, how did the moles of A lost and the moles of A gained in one minute compare?

13. Calculate the moles of product to moles of reactant ratio at equilibrium for your reaction in Model 2.

$$\frac{\text{Moles product}}{\text{Moles reactant}}$$

Model 3 – Comparing Equilibrium Conditions

	Initial moles A	Initial moles B	Percent reacted forward	Percent reacted reverse	Equilibrium moles A	Equilibrium moles B	Ratio of product to reactant
A	10.00	0.00	60.0%	20.0%			
B	5.00	5.00	60.0%	20.0%			
C	0.00	10.00	60.0%	20.0%			
D	8.00	0.00	60.0%	20.0%			
E	0.00	4.00	60.0%	20.0%			
F	10.00	0.00	25.0%	50.0%			
G	5.00	5.00	25.0%	50.0%			
H	0.00	10.00	25.0%	50.0%			
I	8.00	0.00	25.0%	50.0%			
J	0.00	4.00	25.0%	50.0%			

14. Fill in the Table in Model 3.
    - *a.* Enter your data from Model 2 in the appropriate row.
    - *b.* Send a representative from your group to other groups in the class to gather data for other sets of initial conditions. *Note:* Depending on class size, not all of the conditions may have been explored by a group.
15. Based on the data in Model 3, does the reaction reach equilibrium when the moles of A are equal to the moles of B in the container?

16. Based on the data in Model 3, are the equilibrium concentrations of A and B always the same regardless of initial concentrations? *Note:* Compare reactions with the same percentages for the forward and reverse reaction rates.

17. Based on the data in Model 3, does the equilibrium ratio of product to reactant depend on the initial moles of product and reactant? *Note:* Only compare reactions with the same forward and reverse reaction rates. Explain.

18. Based on the data in Model 3, does the equilibrium ratio of product to reactant depend on the percent of the molecules that reacted in the forward and reverse reactions? If yes, describe the relationship.

19. Predict the final product to reactant ratio for the reaction in Model 1 if the initial concentrations of A and B are 15.0 moles and 5.0 moles, respectively, and the percent of molecules reacting in the forward direction is 80.0% while the percent reacting in the reverse direction is 20.0%.

Read This!

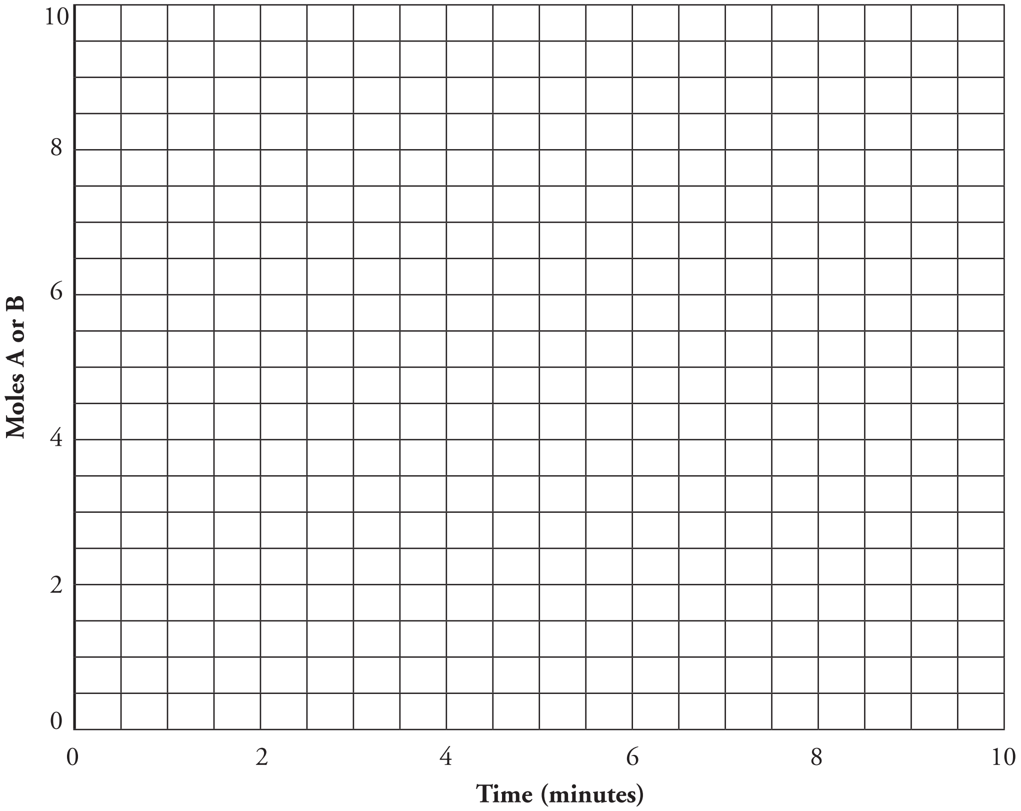
When a reversible reaction reaches equilibrium and the concentrations of the products are significantly higher than those of the reactants, we say the reaction "favors the products." Likewise, if the concentrations of the reactants are higher at equilibrium we say the reaction "favors the reactants."

20. Consider the data collected in Model 3.
    a. Which set of reactions favor the products?
    b. Do reactions that favor the products have a faster forward rate or a faster reverse rate?
    c. Do reversible reactions that favor the products have an equilibrium product to reactant ratio greater than, less than, or equal to one?

21. What is "equal" when a reaction reaches equilibrium?

Extension Questions

23. Using data from Model 2, graph the moles of A and B each minute.



24. How does the shape of the moles vs. time graph communicate that the equilibrium has been established?

25. Predict at least two circumstances (outside influences) that would cause a system in equilibrium to change the concentrations of its reactants or products.

Acids and Bases

How do acids and bases behave in water?

Why?

Acids and bases play an important role in our lives. Numerous biological processes, industrial applications, and even environmental problems are a function of the acidity or basicity (alkalinity) of aqueous solutions. It is therefore important to understand what makes a substance behave as an acid or a base when dissolved in water. In this activity, we will explore the physical and chemical properties of acids and bases.

Model 1 – Arrhenius Acids and Bases

Common Name for Aqueous Solution	Chemical Formula	Found in…	Tastes…	Turns Litmus Paper…	Conducts Electricity?	Acid or Base
Acetic acid	$HC_2H_3O_2(aq)$	Vinegar	Sour	Red	Yes	Acid
Benzoic acid	$HC_7H_5O_2(aq)$	Food preservative	Sour	Red	Yes	Acid
Phosphoric acid	$H_3PO_4(aq)$	Soda pop	Sour	Red	Yes	Acid
Hydrochloric acid	$HCl(aq)$	Stomach acid	Sour	Red	Yes	Acid
Citric acid	$H_3C_6H_5O_7(aq)$	Citrus fruits	Sour	Red	Yes	Acid
Ascorbic acid	$H_2C_6H_6O_6(aq)$	Vitamin C	Sour	Red	Yes	Acid
Magnesium hydroxide	$Mg(OH)_2(aq)$	Milk of magnesia	Bitter	Blue	Yes	Base
Aluminum hydroxide	$Al(OH)_3(aq)$	Antacids	Bitter	Blue	Yes	Base
Barium hydroxide	$Ba(OH)_2(aq)$	Lubricants	POISON	Blue	Yes	Base
Sodium hydroxide	$NaOH(aq)$	Drain cleaner	POISON	Blue	Yes	Base

1. Refer to Model 1.
   a. What is the common chemical name for Vitamin C?
   b. Is Vitamin C classified as an acid or a base?
2. Examine the properties of the Arrhenius acids in Model 1. List three properties that all Arrhenius acids have in common.
3. Examine the chemical formulas for the Arrhenius acids in Model 1. What feature do all the Arrhenius acid chemical formulas have in common?
4. Examine the properties of the Arrhenius bases in Model 1. List two properties that all Arrhenius bases have in common.

5. Examine the chemical formulas for the Arrhenius bases in Model 1. What anion do all the Arrhenius base chemical formulas have in common?

6. A student dissolved a small amount of baking soda in water and tested it with litmus paper. The litmus paper turned blue. Is baking soda likely an acid or a base?

Read This!

In 1903 Svante Arrhenius won the Nobel Prize in Chemistry for defining acids and bases in terms of the ions produced. An Arrhenius acid is any substance that produces hydrogen ions [or hydronium ions (H_3O^+) a hydrogen ion attached to a water molecule] when dissolved in water. An Arrhenius base is any substance that produces hydroxide ions when dissolved in water. While the Arrhenius definitions of acids and bases are useful, they are limited. Johannes Brønsted and Thomas Lowry developed more general definitions for acids and bases using H^+ ion (proton) transfer as the focus.

Model 2 – Brønsted-Lowry Acids and Bases

Reaction 1	$HCl(g)$ (acid)	+	$H_2O(l)$ (base)	$\rightleftarrows$	$H_3O^+(aq)$ + $Cl^-(aq)$
Reaction 2	$NH_3(aq)$ (base)	+	$HF(aq)$ (acid)	$\rightleftarrows$	$NH_4^+(aq)$ + $F^-(aq)$
Reaction 3	$NH_4^+(aq)$ (acid)	+	$H_2O(l)$ (base)	$\rightleftarrows$	$NH_3(aq)$ + $H_3O^+(aq)$
Reaction 4	$F^-(aq)$ (base)	+	$H_2PO_4^-(aq)$ (acid)	$\rightleftarrows$	$HPO_4^{2-}(aq)$ + $HF(aq)$

7. Identify the Brønsted-Lowry acids in Model 2.

   a. Atoms of which element are present in all of the Brønsted-Lowry acids in Model 2?

   b. How can you tell from Reaction 1 that HCl loses an H^+ ion rather than a hydrogen atom when the reaction occurs? *Hint:* Look at the products.

8. For each acid–base reaction in Model 2, describe the role of the Brønsted-Lowry *acid* in the H^+ ion (proton) transfer that occurs.

9. For each acid–base reaction in Model 2, describe the role of the Brønsted-Lowry *base* in the proton (H^+ ion) transfer that occurs.

10. As you saw in Model 1, all Arrhenius bases in Model 1 have an OH^- ion in their chemical formulas. Write a balanced chemical reaction for the reaction of HCl(aq) with OH^-(aq) to illustrate that the hydroxide ion is also a Brønsted-Lowry base.

STOP

11. If you reverse Reaction 1 in Model 2, the following reaction is obtained.

    $H_3O^+(aq) + Cl^-(aq) \rightleftarrows HCl(aq) + H_2O(l)$

    a. For the reaction above, which reactant is acting like a Brønsted-Lowry acid? How can you tell?

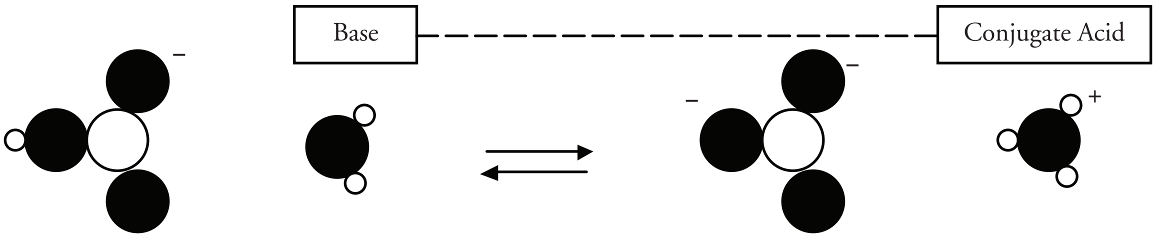
    b. For the reaction above, which reactant is acting like a Brønsted-Lowry base? How can you tell?

12. Write the reverse reactions for Reactions 2 and 3 in Model 2. Label the Brønsted-Lowry acid and base reactants for each reaction.

    Reaction 2

    Reaction 3

Model 3 – Conjugate Acid–Base Pairs



$HCO_3^{1-}(aq) + H_2O(l) \rightleftarrows CO_3^{2-}(aq) + H_3O^{1+}(aq)$

13. All acid–base reactions have two conjugate acid–base pairs. One conjugate acid–base pair in the reaction in Model 3 is H_3O^+/H_2O. List the other acid–base pair in the reaction.

14. Why is HCO_3^- considered the "acid" part of the pair in the reaction in Model 3?

15. Why is CO_3^{2-} considered the "base" part of the pair in the reaction in Model 3?

16. The *"Read This!"* box before Model 2 calls the transfer of a H^+ ion a "proton transfer." Explain why "H^+ ion" and "proton" are synonymous.

17. Examine the charges on the species in the Model 3 reaction. Why does the charge on the carbon-containing ion change from –1 to –2?

18. Using the list of substances below, select pairs that are conjugate acids and bases. Enter the pairs in the tables below. The first acid–base pair has been entered for you. Note that you may use a substance more than once or not at all.

H_3PO_4
H_2O
$HC_2H_3O_2$
H_3O^+
NH_2^-
PO_4^{3-}
NO_2^-
CO_2
HPO_4^{2-}
$C_2H_3O_2^-$
CO_3^{2-}
OH^-
H_2CO_3
NH_3
$H_2PO_4^-$

	Acid	Conjugate Base
1	H_3PO_4	$H_2PO_4^-$
2		
3		
4		

	Acid	Conjugate Base
5		
6		
7		

STOP

19. Write the formula for the conjugate base of each of the following acids. *Hint:* Be sure to consider charges.

a. HSO_3^- *b.* HF *c.* HS^-

20. Write the formula for the conjugate acid of each of the following bases. *Hint:* Be sure to consider charges.

a. SO_3^{2-} *b.* F^- *c.* HS^-

21. For the following reactions, label the acid and base in the reactants, and the conjugate acid and conjugate base in the products.

$HCO_3^-(aq) + NH_3(aq) \rightleftarrows NH_4^+(aq) + CO_3^{2-}(aq)$

$HCO_3^-(aq) + HCl(aq) \rightleftarrows Cl^-(aq) + H_2CO_3(aq)$

22. Is the role of a conjugate acid in the reverse direction the same as the role of an acid in the forward direction? Explain.

Extension Questions

23. Some of the substances used in this activity can behave as both an acid and a base. These substances are said to be **amphiprotic** or **amphoteric**. Provide two examples of amphoteric substances found in this activity.

24. Water is an amphoteric substance. In any sample of water some of the molecules perform acid–base reactions with each other. This is called the **autoionization** of water. Write a chemical reaction showing the acid–base reaction of two water molecules.

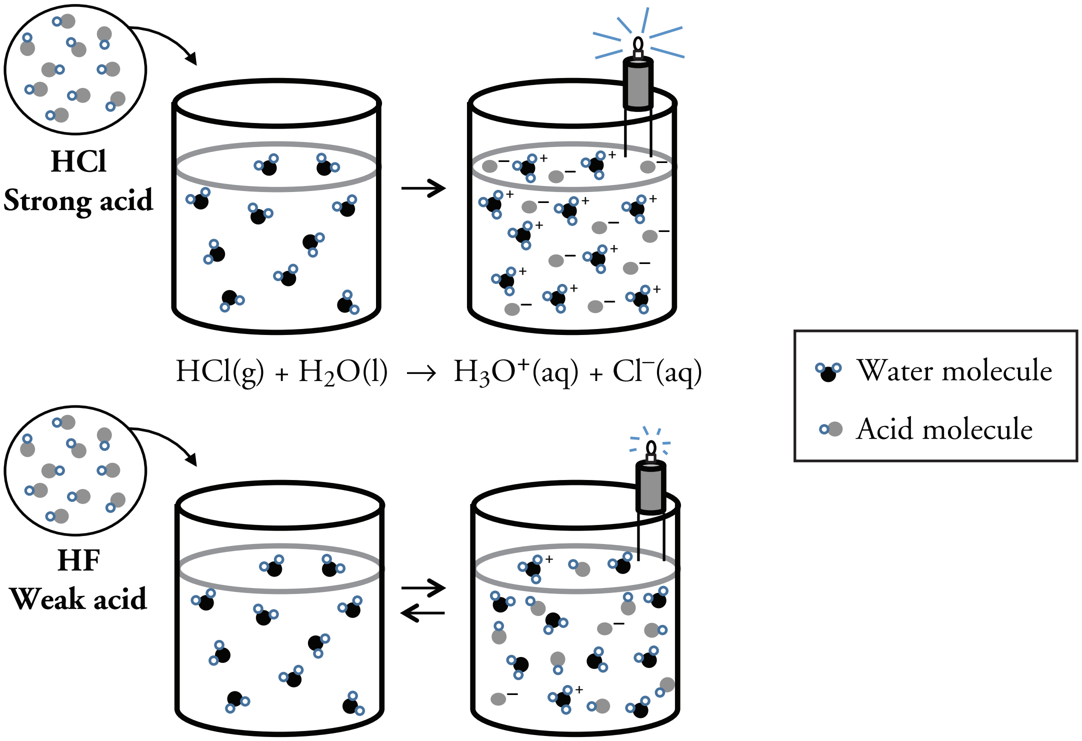
Strong versus Weak Acids

What makes a strong acid strong?

Why?

Acids are substances that surround us in our everyday life. The uses of acids range from providing essential nutrients for our bodies to dissolving metals. Some acids are safe to handle with our bare hands or even use in food preparation. Other acids will severely burn human skin. It is important to understand how these substances can all be acids and yet have such different properties.

Model 1 – Acid Strength and Conductivity

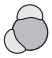
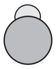


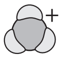
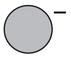
$HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$

$HF(g) + H_2O(l) \rightleftarrows H_3O^+(aq) + F^-(aq)$

Note: Excess water molecules in the solutions are not shown.

1. Examine the symbols in Model 1. Match each symbol with its correct meaning.

______  ______ 

______  ______ 

a. Water molecule

b. Acid molecule

c. Conjugate base ion

d. Hydronium ion

2. Examine the strong and weak acid solutions in Model 1.
   a. What product do the solutions have in common?

   b. Use a complete sentence to explain the formation of the product in part *a* from an acid molecule and a water molecule.

3. Assume that solutions of HCl and HF similar to those in Model 1 are prepared, and infinitesimally small samples are collected and analyzed to determine the amount of ionization that occurs. Based on the data below, calculate the percent ionization for each acid solution. Solution A has been completed for you.

	Solution	**Initial number of acid molecules**	**Number of acid molecules that reacted**	$\frac{\textbf{Molecules reacted}}{\textbf{Initial number of molecules}}$	**Percent ionization**
A	0.06 M HCl	40	40	$\frac{40}{40}$	100%
B	0.06 M HF	40	8		
C	0.03 M HCl	20	20		
D	0.03M HF	20	4		

Read This!

Electrolytes are substances that dissolve in water to produce ions in solution. The presence of ions allows a solution to conduct an electrical current. Ions may be produced because the substance that dissolves is ionic (like salt), or because the substance reacts with water to produce ions (as is the case with acids). The more ions that are formed in solution, the stronger the electrolyte. **Nonelectrolytes** are substances whose aqueous solutions do not contain ions and therefore do not conduct an electrical current.

4. Which solution in Model 1, the strong or weak acid, is a better conductor of electricity? Provide evidence from Model 1 for your answer.

5. Based on the data in Model 1 and the table in Question 3, describe the relationship between:

   a. the percent ionization of the acid and the conductivity of the solution.

   b. the conductivity of the solution and the strength of the electrolyte (acid strength).

6. Consider the conductivity data shown in Model 1 and the ionization data in Question 3.

   a. Is HCl a strong acid or a weak acid? Explain in terms of percent ionization.

   b. Is HF a strong acid or a weak acid? Explain in terms of percent ionization.

7. Does a change in concentration affect the strength of an acid? Use the information in Question 3 to provide specific evidence to support your answer.

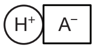
8. In one of the reactions in Model 1 there is a single arrow (→). In the other reaction there is a double arrow (⇄). What do these symbols imply:

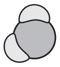
   a. about the extent to which the reaction occurs?

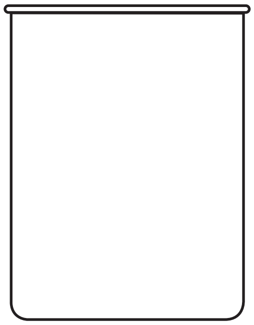
   b. about the strength of the acid?

9. A student states "A solution of 4 M sulfuric acid (H_2SO_4) is a stronger acid than a 1 M solution of sulfuric acid." Construct a well-thought out response to help this student improve his understanding.

10. In the beaker below, draw a representation to show 10 molecules of a weak acid dissolved in water with 20% ionization. Include only the water molecules that react, not the excess water molecules in the solution.

Molecular acid = 

Water = 



11. You have conductivity meters in 1 M solutions of HNO_3, HNO_2, and $HC_2H_3O_2$. The 1 M HNO_3 light bulb is bright, the 1 M HNO_2 light bulb is giving off some light, and the 1 M $HC_2H_3O_2$ is very dim. Rank the solutions in order of acid strength based on this information.

12. Based on your answer to Question 11, write balanced chemical equations for HNO_3 and HNO_2 reacting with water as they are mixed into an aqueous solution. Use single or double arrows as appropriate.

Extension Questions

Model 2 – The Meaning of K_a

$$HA(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + A^-(aq) \qquad K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

13. In Model 2, does HA represent a weak acid or a strong acid? What evidence found in the model supports your answer?

14. Compare the equation above that starts out "K_a =" to other equilibrium constant expressions you have seen.

    a. Is K_a calculated in the same manner as other K_{eq} values?

    b. What molecule in the reaction has been left out of the K_a expression? Give a reason why this molecule was ignored in calculating K_a.

15. Consider what you learned in Model 1 about the extent to which weak acids react with water. Is the value of K_a for a weak acid likely to be greater than or less than 1? Explain your answer in terms of the numbers that might be used in the equation in Model 2.

16. Is the value of K_a for a strong acid greater than or less than 1? Explain your answer in terms of the numbers that might be used in the equation.

17. Consider the weak acid ammonium (NH_4^+).

    a. Write the acid dissociation reaction for NH_4^+ using Model 1 as your guide. Pay close attention to the arrow (single or double) you use.

    b. Write the K_a expression for NH_4^+ using Model 2 and your equation above as a guide.

Calculating pH

How is pH related to the concentration of hydronium ions?

Why?

In biology and other science courses pH is introduced as a way to quantify the acidity or basicity of a solution. This property can be measured using a pH probe or with an indicator paper strip that changes color at different pH values. But, what is actually being measured? We know that a pH of 7 is neutral, below 7 is acid, and above 7 is base, but why? What in the solution is the paper strip or probe actually reacting with?

Model 1 – Ion Concentrations for Acids and Bases

Beaker	Solution	Acidic, Basic or Neutral?	$[H_3O^+]$	$[OH^-]$	$[H_3O^+] \times [OH^-]$
1	0.10 M HCl(aq)	Acidic	1.0×10^{-1} M	1.0×10^{-13} M	
2	0.0010 M HCl(aq)	Acidic	1.0×10^{-3} M	1.0×10^{-11} M	
3	0.000010 M HCl(aq)	Acidic	1.0×10^{-5} M	1.0×10^{-9} M	
4	0.0000010 M HCl(aq)	Acidic	1.0×10^{-6} M	1.0×10^{-8} M	
5	0.00000010 M HCl(aq)	Neutral	1.0×10^{-7} M	1.0×10^{-7} M	
6	0.00000010 M NaOH(aq)	Neutral	1.0×10^{-7} M	1.0×10^{-7} M	
7	0.0000010 M NaOH(aq)	Basic	1.0×10^{-8} M	1.0×10^{-6} M	
8	0.00010 M NaOH(aq)	Basic	1.0×10^{-10} M	1.0×10^{-4} M	
9	0.010 M NaOH(aq)	Basic	1.0×10^{-12} M	1.0×10^{-2} M	
10	0.10 M NaOH(aq)	Basic	1.0×10^{-13} M	1.0×10^{-1} M	

1. What does the symbol $[H_3O^+]$ in Model 1 indicate?

2. In Beaker 2, which ion has a higher concentration, hydronium ion or hydroxide ion?

3. Describe how the concentration of hydronium ion was calculated for Beaker 3 in Model 1 from the concentration of the acid.

4. Describe how the concentration of hydroxide ion was calculated for Beaker 8 in Model 1 from the concentration of the base.

5. Which ion, hydronium or hydroxide, has a higher concentration in an acidic solution?

6. Which ion, hydronium or hydroxide, is more concentrated in a neutral solution?

7. Which statement is true for basic solutions?

   a. The hydroxide ion concentration must be less than 1.0×10^{-7} M.

   b. The hydroxide ion concentration must be more than 1.0×10^{-7} M.

   c. The hydroxide ion concentration must be more than or equal to 1.0×10^{-7} M.

8. A student makes the following statement on an exam: “Acidic solutions contain hydronium ions, while basic solutions contain hydroxide ions.” Is the student’s statement correct based on the information in Model 1? Explain.

9. Calculate the quantity $[H_3O^+] \times [OH^-]$ for each of the 10 beakers in Model 1. Divide the work among the members in your group.

10. If you know the hydronium ion concentration, $[H_3O^+]$, of a solution, how could you determine the hydroxide ion concentration, $[OH^-]$?

11. A solution has a hydroxide ion concentration of 1.0×10^{-3} M.

    a. What is the hydronium ion concentration in the solution? (Show your work.)

    b. Is the solution acidic, neutral or basic? How do you know?

12. A solution has a hydroxide ion concentration of 4.79×10^{-3} M.

    a. What is the hydronium ion concentration in the solution? (Show your work.)

    b. Is the solution acidic, neutral or basic? How do you know?

Read This!

The value 1.0×10^{-14} is the equilibrium constant for the autoionization of water (K_w).

$$H_2O + H_2O \rightleftarrows H_3O^+(aq) + OH^-(aq) \qquad K_w + 1.0 \times 10^{-14}$$

This equilibrium occurs in all aqueous solutions (acidic, basic, and neutral). The results of this equilibrium are as follows:

1. All aqueous solutions have some detectable concentration of both hydronium and hydroxide ions.
2. The product of these ion concentrations is always K_w.

$$K_w = [H_3O^+] \times [OH^-] = 1.0 \times 10^{-14}$$

Model 2 – A Crash Course in Logarithms

$\log 1 = 0$

$\log 10 = 1$

$\log 100 = 2$

$\log 1000 = 3$

$\log (1.0 \times 10^4) = 4$

$\log 0.1 = -1$

$\log 0.01 = -2$

$\log 0.001 = -3$

$\log (1.0 \times 10^{-4}) = -4$

$\log (1.0 \times 10^{-8}) = -8$

13. Using the examples in Model 2, explain how logarithms are calculated in terms of “factors of ten.”

14. What would be the logarithm of one million? (Do NOT use your calculator.)

15. Take out your scientific calculator.
    a. Enter at least three of the examples shown in Model 2 into your calculator to verify that you know how to find the logarithm of a number.

    b. Use your calculator to find the logarithm of 250.

    c. The number 250 is between 100 and 1000. Explain why your calculator gave you an answer between 2 and 3 for the log of 250. *Hint:* Think about “factors of ten.”

16. First estimate the answer for each of the following. Then, find the answer using your calculator to check your estimate.

    a. 7800 *b.* 0.045 *c.* 3.4×10^9 *d.* 7.2×10^{-4}

Model 3 – Logarithms and pH

	1	2	3	4
Solution	**$[H_3O^+]$ (Decimal notation)**	**$[H_3O^+]$ (Scientific notation)**	**$\log [H_3O^+]$**	**pH**
A	0.010 M	1.0×10^{-2} M	$\log (1.0 \times 10^{-2}) = -2.0$	2.0
B	0.0055 M	5.5×10^{-3} M	$\log (5.5 \times 10^{-3})$	
C		1.0×10^{-3} M	$\log (1.0 \times 10^{-3}) = -3.0$	3.0
D	0.00010 M		$\log (1.0 \times 10^{-4}) = -4.0$	4.0
E	0.000027 M	2.7×10^{-5} M	$\log (2.7 \times 10^{-5})$	

17. Columns 1 and 2 in Model 3 both give the molar concentration of hydronium ion in solution.
    a. What is the difference in the way the first two columns express this data?

    b. Fill in the missing values in columns 1 and 2 of Model 3.

18. Estimate the missing logarithms for solutions B and E in Model 3. Then verify the answers using a calculator.

19. Using the examples given in Model 3, write a sentence or a mathematical equation that describes how to calculate pH from the hydronium ion concentration of a solution.

20. Fill in the missing pH values in column 4 of Model 3.

21. Calculate the pH of a solution that has a hydronium ion concentration of:
    a. 1×10^{-8} M *b.* 0.007 M

22. Discuss in your group how you would find the hydronium ion concentration in a solution if you were given the pH. Check your procedure using several examples from Model 3.

23. Calculate the hydronium ion concentration in solutions with a pH of:
    a. 6.0 *b.* 5.43

24. Why does neutral water have a pH of 7?

25. Which solution has a greater hydronium ion concentration, one that has a pH of 4 or one that has a pH of 8? Explain.

26. A student makes the following statement on an exam:

"A solution with pH = 1 is twice as concentrated in hydronium ions as a solution with pH = 2."

Explain why this statement is not correct, and write a sentence that describes the correct relationship.

Extension Questions

Model 4 – pH and pOH

Solution	**$[H_3O^+]$**	**$[OH^-]$**	**pH**	**pOH**	**pH + pOH**
A	1×10^{-3} M	1×10^{-11} M	3.0	11.0	
B	1×10^{-9} M	1×10^{-5} M	9.0	5.0	
C	5.2×10^{-3} M	1.9×10^{-12} M	2.28	11.72	
D				3.68	
E			9.28		
F		3.02×10^{-3} M			

27. Look at the examples in Model 4. If you know the concentration of hydroxide ion, $[OH^-]$, in a solution, how can you determine the pOH?

28. Consider the data in Model 4.

    a. Calculate pH + pOH for solutions A, B and C.

    b. How could you determine the pH of a solution if you know the pOH?

29. Fill in all of the missing values in Model 4 .
30. Calculate the $[OH^-]$ and pOH of a solution that has a $[H_3O^+]$ of 1×10^{-4} M.

Oxidation and Reduction

What happens when electrons are transferred in a chemical reaction?

Why?

Silver tarnishes when it comes in contact with sulfur compounds in the air. Copper gets coated in beautiful green patina as it ages. Metals rust or corrode in the presence of air and water. Minerals (ionic compounds) found in ore can be decomposed with the use of electricity to produce pure metals and nonmetals. All of these reactions are examples of oxidation and reduction, otherwise known as **redox** reactions. In this activity you will explore what is happening at the atomic level in redox reactions.

Model 1 – Redox Reactions

Redox Reactions

A. $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

B. $2I^{-}(aq) + S_2O_8^{2-}(aq) \rightarrow I_2(s) + 2SO_4^{2-}(aq)$

C. $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

D. $4H^{+}(aq) + MnO_4^{-}(aq) + 3Fe^{2+}(aq) \rightarrow 3Fe^{3+}(aq) + MnO_2(aq) + 2H_2O(l)$

Nonredox Reactions

E. $HCl(g) + H_2O(l) \rightarrow H_3O^{+}(aq) + Cl^{-}(aq)$

F. $2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

G. $Ba^{2+}(aq) + 2OH^{-}(aq) \rightarrow Ba(OH)_2(s)$

H. $2AgNO_3(aq) + CaCl_2(aq) \rightarrow Ca(NO_3)_2(aq) + 2AgCl(s)$

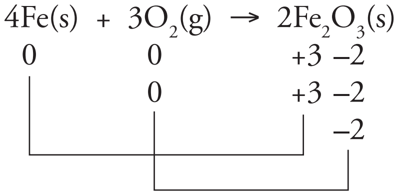
1. What two types of reactions are shown in Model 1?

2. Examine the redox and nonredox reactions in Model 1. Is/are there any feature(s) in the redox reactions that would allow you to identify them as redox reactions? If yes, use specific examples from Model 1 to support your answer.

3. In the space under each reaction in Model 1, write the oxidation number for every atom. Divide the work among your group members. An example is shown here:

$$\begin{array}{ccccc} 4\mathrm{Fe(s)} & + & 3\mathrm{O_2(g)} & \rightarrow & 2\mathrm{Fe_2O_3(s)} \\ 0 & & 0 & & +3\ -2 \\ & & 0 & & +3\ -2 \\ & & & & \quad -2 \end{array}$$

4. Identify any elements that changed oxidation number in the reactions in Model 1. Connect the starting and ending oxidation numbers with a line. An example is shown here:



5. Based on the oxidation number analysis you just performed for the reactions in Model 1, are there any features of the redox reactions that would allow you to identify them as redox reactions? If yes, use specific examples from Model 1 to support your answer.

6. Identify the following reactions as either redox or nonredox using oxidation numbers as evidence.

   a. $\mathrm{Pb(NO_3)_2(aq)} + 2\mathrm{NaI(aq)} \rightarrow \mathrm{PbI_2(s)} + 2\mathrm{NaNO_3(aq)}$

   b. $2\mathrm{H_2O} \rightarrow 2\mathrm{H_2} + \mathrm{O_2}$

   c. $\mathrm{CH_4} + 2\mathrm{O_2} \rightarrow 2\mathrm{H_2O} + \mathrm{CO_2}$

   d. $\mathrm{HCl} + \mathrm{NaOH} \rightarrow \mathrm{H_2O} + \mathrm{NaCl}$

Read This!

The process of oxidation and reduction can be thought of as a transfer of electrons from one atom to another. Thus, one atom gives up electrons and the other atom gains them. As a result of this process, the oxidation numbers of both atoms change. All redox reactions can be divided up into two reactions—an **oxidation half-reaction** and a **reduction half-reaction**. This allows for better understanding of the electron transfer process.

Model 2 – Half Reactions

A. $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

ox: $Zn \rightarrow Zn^{2+} + 2e^-$

red: $Cu^{2+} + 2e^- \rightarrow Cu$

B. $2I^-(aq) + S_2O_8^{2-}(aq) \rightarrow I_2(s) + 2SO_4^{2-}(aq)$

ox: $2I^- \rightarrow I_2 + 2e^-$

red: $S_2O_8^{2-} + 2e^- \rightarrow 2SO_4^{2-}$

C. $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

ox: $Fe \rightarrow Fe^{3+} + 3e^-$

red: $O_2 + 4e^- \rightarrow 2O^{2-}$

D. $4H^+(aq) + MnO_4^-(aq) + 3Fe^{2+}(aq) \rightarrow 3Fe^{3+}(aq) + MnO_2(aq) + 2H_2O(l)$

ox: $Fe^{2+} \rightarrow Fe^{3+} + e^-$

red: $4H^+ + MnO_4^- + 3e^- \rightarrow MnO_2 + 2H_2O$

7. What does the "e^-" symbol represent in the oxidation and reduction half-reactions shown in Model 2?

8. Look at the oxidation half-reactions in Model 2.

   a. Which of the following types of particles may undergo oxidation? (Circle all that apply.)

   Neutral atoms/molecules   Cations   Anions

   b. Are electrons lost or gained by an atom during the process of oxidation?

   c. Does the oxidation number of an atom involved in the process of oxidation increase or decrease?

9. Look at the examples of reduction in Model 2.

   a. Which of the following types of particles undergo reduction? (Circle all that apply.)

   Neutral atoms/molecules   Cations   Anions

   b. Are electrons lost or gained by an atom during the process of reduction?

   c. Does the oxidation number of an atom involved in the process of reduction increase or decrease?

10. Consider the word “reduction” as it is used in the English language. In reduction half-reactions, what is “reduced”? Use the examples in Model 1 to verify your answer.

Read This!

Oxidation occurs when atoms lose electrons. **Reduction** occurs when atoms gain electrons. These two processes always occur together. In other words, you can’t just let electrons loose into space—they must be grabbed by some other atom. Likewise, you can’t just grab electrons from space—they must be taken from some other atom. An easy way to remember these processes is to remember the phrase “LEO the lion goes GER.”

LEO = **L**oss of **E**lectrons is **O**xidation   GER = **G**ain of **E**lectrons is **R**eduction

11. Consider the incomplete half-reactions below.

    a. Use oxidation numbers to identify the reactions below as oxidation or reduction.

    b. Place the correct number of electrons on the appropriate side of the reaction to complete the equation.

    $I_2 \rightarrow 2I^-$ $Cr^{2+} \rightarrow Cr^{3+}$

    $Sr \rightarrow Sr^{2+}$ $ClO_2^- + H_2O \rightarrow ClO_3^- + 2H^+$

STOP

12. Consider Reaction A in Model 2. Show that the two half-reactions can be added together to give the overall redox reaction. *Hint:* Consider how you would add two equations together in algebra.

13. Show how the two half-reactions for Reaction B in Model 2 can be added together to give the overall redox reaction.

14. Recall that the same number of electrons that are lost by atoms during oxidation must be gained by atoms during reduction. Show how the half-reactions for Reactions C and D in Model 2 can be added together to give the overall redox reactions shown.

Extension Questions

15. Are electrons conserved in redox reactions? Explain.

16. When iron is exposed to oxygen, it forms rust as described by the following equation. In this reaction oxygen is acting as the **oxidizing agent**.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

a. What element was oxidized in the reaction above?

b. Explain why oxygen is considered the oxidizing agent in this reaction? *Hint:* Consider the purpose of an "insurance agent" or a "real estate agent."

c. What is the **reducing agent** in the reaction above? Explain.

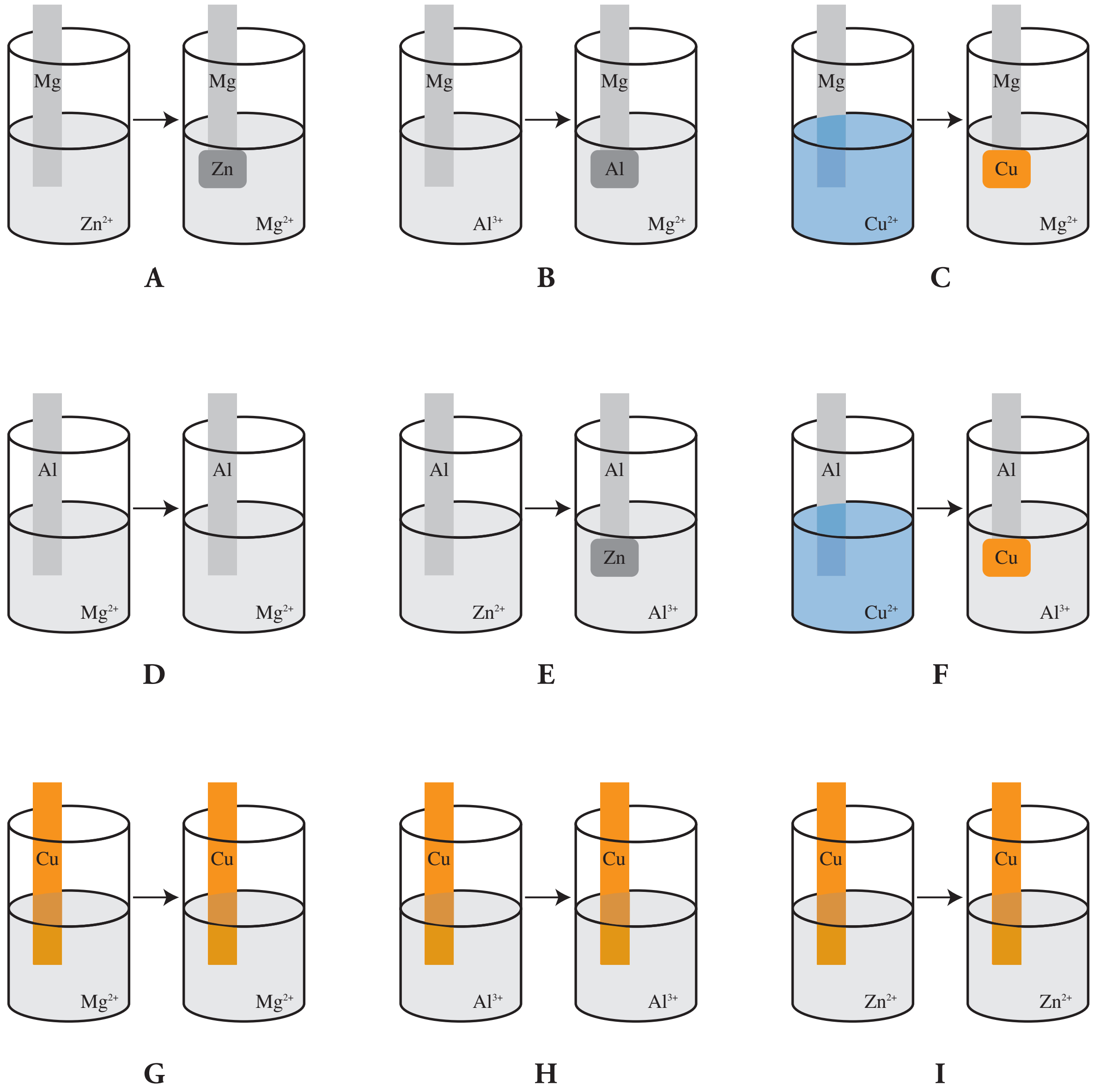
The Activity Series

Which metals lose their electrons more easily?

Why?

One of the chemical properties of metals is that they form cations in chemical reactions. This requires them to lose their electrons, or be oxidized. However, electrons need to go somewhere, so some metals will tend to stay in their neutral state. Which metals are better at making cations and which are better staying neutral? That is the question we will explore in this activity.

Model 1 – Reactivity of Metals



Note: Water molecules and spectator ions have been left out of these diagrams for ease of analysis.

1. Which ions, sodium (Na^+) or nitrate (NO_3^-), are more likely to be the missing “spectator ions” in the beakers of Model 1? Explain your reasoning.

2. Examine the diagrams in Model 1.
   - *a.* List two pieces of evidence from Experiment A in Model 1 that indicate a reaction has occurred.
   - *b.* List two pieces of evidence from Experiment G in Model 1 that indicate no reaction occurred.

3. Circle the letter below each experiment in Model 1 that resulted in a reaction.
   - *a.* Write a single replacement reaction under the beakers in each experiment to illustrate the reaction. Ignore the spectator ions.
   - *b.* Circle the species in each of the reactant beakers that underwent oxidation.
   - *c.* Draw an arrow from one species in each of the reactant beakers to another species in the reactant beaker to show how the electrons were transferred in the reaction.

4. Find the two experiments in Model 1 that involve aluminum and magnesium.
   - *a.* Will aluminum give its electrons to magnesium?
   - *b.* Will magnesium give its electrons to aluminum?
   - *c.* Which metal, aluminum or magnesium, is better at giving up electrons?

5. Find the two experiments in Model 1 that involve aluminum and copper.
   - *a.* Will aluminum give its electrons to copper?
   - *b.* Will copper give its electrons to aluminum?
   - *c.* Which metal, aluminum or copper, is better at giving up electrons?

6. Predict what might happen if you put a piece of metal in a solution of its own ion (copper metal in a Cu^{2+} solution or magnesium metal in a Mg^{2+} solution).

STOP

7. An **active metal** readily gives up its electron(s) and is oxidized. There are four metals involved in the reactions of Model 1—magnesium, aluminum, copper, and zinc. Rank these metals from "least active" to "most active" based on the data in Model 1. Support your ranking with an explanation.

Least active ——————————————→ Most active

8. Using your ranking in Question 7, draw a reaction diagram like those in Model 1 for the combinations below to illustrate whether a reaction occurred or not.
   a. Zinc metal in Mg^{2+} solution
   b. Zinc metal in Cu^{2+} solution

9. In chemistry we say "magnesium ions replace copper ions in solution" when a reaction occurs. Using your ranking in Question 7, determine which of the statements below are true and which are false.
   a. Magnesium ions replace aluminum ions in solution.
   b. Copper ions replace zinc ions in solution.
   c. Zinc ions replace magnesium ions in solution.

Model 2 – The Activity Series

10. The activity series shown in Model 2 to the right is a ranking, similar to the one you did in Question 7, of several metals.

    a. Are the more active metals at the top or at the bottom? Explain.

    b. Label Model 2 with “most active” and “least active” in the appropriate locations.

11. Use the activity series in Model 2 to predict whether a reaction will occur when the following reactants are mixed.

    a. $\mathrm{Al(s)} + \mathrm{Pb^{2+}(aq)} \rightarrow$

    b. $\mathrm{Cu^{2+}(aq)} + \mathrm{Fe(s)} \rightarrow$

    c. $\mathrm{Au(s)} + \mathrm{CuCl_2(aq)} \rightarrow$

    d. $\mathrm{KNO_3(aq)} + \mathrm{Cr(s)} \rightarrow$

Li
Rb
K
Ba
Ca
Na
Mg
Al
Mn
Zn
Cr
Fe
Co
Ni
Sn
Pb
H
Cu
Ag
Hg
Pt
Au

Activity Series of Metals

12. Although hydrogen is not a metal, it is included in the activity series. Consider reactions *a–c* and predict whether the metal shown in each case will react with acid. If the metal will react, complete and balance the equation.

    a. $\mathrm{Zn(s)} + \mathrm{HCl(aq)} \rightarrow$

    b. $\mathrm{Fe(s)} + \mathrm{HCl(aq)} \rightarrow$

    c. $\mathrm{Cu(s)} + \mathrm{HCl(aq)} \rightarrow$

13. In old westerns, we often see a desperate prospector get very excited when he sees a vein of gold in the wall of his mine. It is true that gold, silver, and copper are typically found in nature as metals. On the other hand, potassium, calcium, and magnesium are never found as metals in nature. They are only found as ions dissolved in water (oceans and ground water) or in ionic compounds in rocks (ores). Explain these observations of nature using the ideas of the activity series.

Extension Questions

14. Plumbers often use a “dielectric union” joint to join pipes of different types. For example copper pipes in a house might need to be joined with lead pipes in the main water supply. The dielectric union is a plastic joint which will not conduct electricity. Propose an explanation for why a copper pipe can’t simply be welded directly to a lead pipe.

15. Ships and recreational boats often have large chunks of zinc attached to their hulls in order to prevent corrosion (oxidation) of the metal parts in the hull or engine. The latter are typically made of iron alloys. Explain why zinc is a good metal to use for this purpose.

16. Shown below is an activity series for nonmetals that ranks the ability of different nonmetals to accept electrons in a redox reaction.

    (Least active) P < S < I < Br < O < Cl < F (Most active)

    The activity of chlorine and iodine, for example, can be compared in the following reactions.

    $Cl_2(g) + MgBr_2(aq) \rightarrow MgCl_2(aq) + Br_2(l)$ Will occur spontaneously.

    $I_2(s) + 2NaF(aq) \rightarrow 2NaI(aq) + F_2(g)$ Will NOT occur spontaneously.

    Predict if the combinations of reactants in *a–d* will result in a chemical reaction. If a reaction will occur, complete and balance the equation.

    a. $F_2(g) + NaCl(aq) \rightarrow$

    b. $I_2(s) + Br^-(aq) \rightarrow$

    c. $ZnS(s) + O_2(g) \rightarrow$

    d. $Cl_2(g) + I^-(aq) \rightarrow$

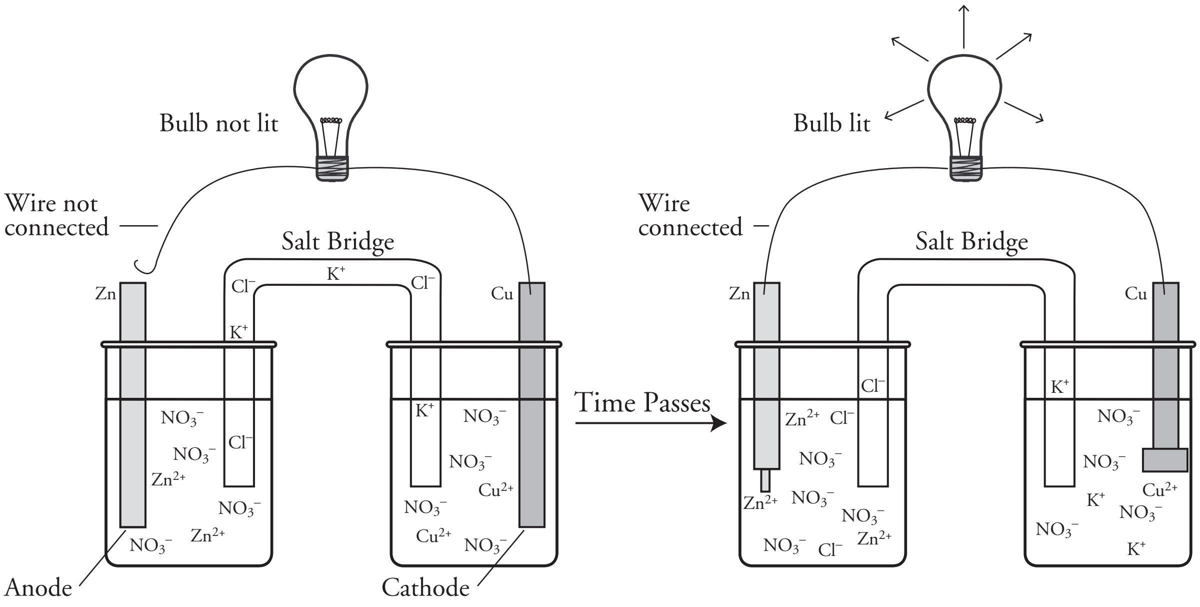
Batteries

How does a battery (voltaic cell) work?

Why?

When we use portable devices like MP3 players and cell phones we need a ready source of electricity to provide a flow of electrons. Batteries are the common solution to this challenge. In a battery or voltaic cell, oxidation and reduction reactions provide electrons which power our devices. In this activity we will explore the chemistry of voltaic cells or batteries.

Model 1 – Voltaic Cell



Before the wire is connected

A few minutes after the wire was connected

1. Consider the reaction in Model 1. Notice that there are two zinc ions (Zn^{2+}) in the beaker on the left before the wire is connected. Explain why the number of nitrate ions (NO_3^-) present in that beaker is correct.

2. Examine the system in Model 1 both before the wire is connected and after it is connected. Identify two specific pieces of evidence that a chemical reaction has occurred as time passes with the wire connected.

3. Examine the diagram in Model 1.

   a. Which piece of solid metal loses mass (gets smaller) as the reaction proceeds?

   b. Does the number of zinc ions (Zn^{2+}) in solution increase or decrease as the reaction proceeds?

   c. Circle the half-reaction below that represents the change in the metal identified in part *a*.

   $Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

   $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

   d. Is the reaction circled in part *c* an oxidation or reduction reaction?

4. Examine the diagram in Model 1.

   a. Which piece of solid metal is gaining mass as the reaction proceeds?

   b. Where do those metal atoms come from? Explain.

   c. Circle the half-reaction below that represents the change in the metal identified in part *a*.

   $Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

   $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

   d. Is the reaction circled in part *c* an oxidation or reduction reaction?

5. Electricity is the flow of electrons. Look back at Model 1. In which diagram can the electrons flow through the wire, the one when the **bulb is not lit** or the one when the **bulb is lit**? (Circle one.) Explain your answer.

6. Based on your answers in Questions 3 and 4, which piece of solid metal is giving up electrons, and therefore losing them into the wire?

7. On the drawing of the voltaic cell in Model 1, draw an arrow to depict the direction that the electrons are traveling through the wire.

8. Consider the reactions occurring in Model 1.

   a. What type of half-reaction (oxidation or reduction) is occurring at the piece of metal labeled **anode** in Model 1?

   b. What type of half-reaction (oxidation or reduction) is occurring at the piece of metal labeled **cathode** in Model 1?

   c. Explain how the phrase "an ox and a red cat" can help students remember the type of half-reaction that occurs at each electrode in an electrochemical cell.

9. Explain how the direction of electron flow in a voltaic cell is consistent with what you would predict from the activity series?

10. Draw an unconnected voltaic cell similar to the one on the left side of Model 1 using iron and silver as electrodes. The solutions should include silver ions (Ag^+), iron ions (Fe^{3+}), and nitrate ions (NO_3^-). Use a salt bridge identical to that in Model 1.

11. Use the activity series of metals to determine which metal in the voltaic cell in Question 10 should be the anode. Explain your choice.

12. Draw an arrow on your diagram in Question 10 to indicate the direction of electron flow through the voltaic cell once the wire is connected.

13. Use Model 1 to complete the table.

	Initially	**After a Few Minutes**
Number of zinc ions (Zn^{2+}) dissolved in solution		
Number of copper ions (Cu^{2+}) dissolved in solution		
Number of nitrate ions (NO_3^-) dissolved in solution		
Number of potassium ions (K^+) dissolved in solution		
Number of chloride ions (Cl^-) dissolved in solution		

14. Even though ions and electrons move around in a voltaic cell, the cell must stay electrically neutral.

    a. Explain how the anode half-cell in Model 1 remains electrically neutral (no charge) even though zinc ions are being formed from neutral zinc metal. Refer to the table in Question 13 to support your answer.

    b. Explain how the cathode half-cell in Model 1 remains electrically neutral (no charge) even though copper ions are being removed from the solution. Refer to the table in Question 13 to support your answer.

    c. What is the role of the salt-bridge in a voltaic cell?

Extension Questions

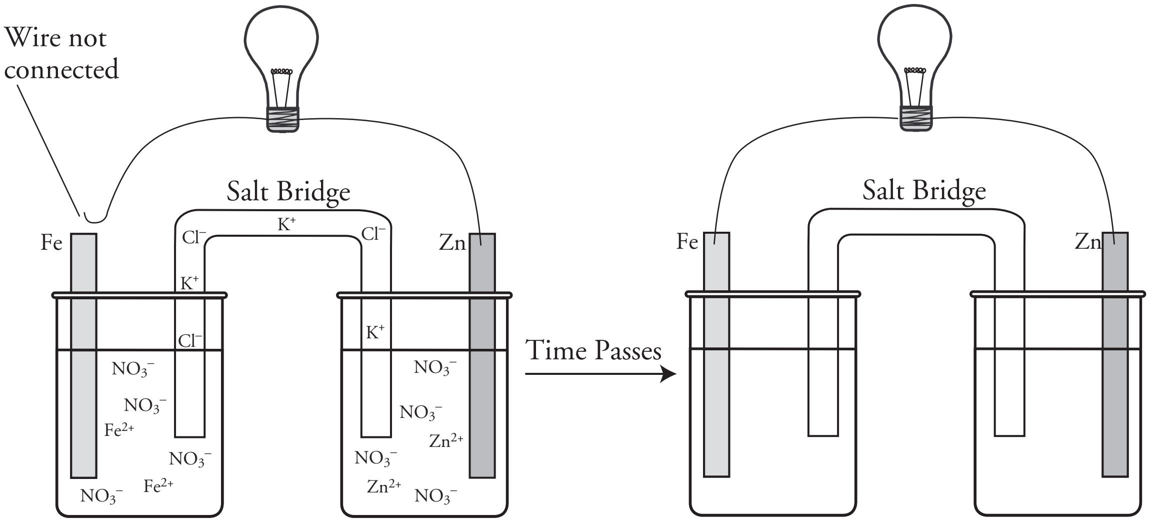
15. Work with your group to apply everything you have learned about batteries to label the voltaic cell diagram below. Use the path and direction that the electrons are traveling to help you.

    a. Label the following items on the diagram.

Site of oxidation	Site of reduction
Anode	Cathode

    b. Complete the "few minutes after" drawing to show what ions would be in the beakers and the salt bridge, and how the electrodes may have changed.

    c. Write the oxidation and reduction half-reactions for the voltaic cell.



Before the wire is connected

A few minutes after the wire was connected

16. Propose a reason why it is necessary to place the metal electrodes in solutions of their own ions to make a battery.

Student Assessment Questions – Safety First

Questions

1. The best footwear for use in the laboratory is
   - *a.* Sandals.
   - *b.* Open-toe shoes.
   - *c.* Closed-toe shoes.
   - *d.* Shoes appropriate for the weather.

2. True or False—Horseplay or practical jokes in the laboratory are okay. ____________________

3. Fill in—After you have finished using scalpels, ______________________________________.

Student Assessment Questions – Fundamentals of Experimental Design

Questions

1. Consider the research question, “Does changing the volume of a gas affect the gas pressure?” Identify the independent and dependent variables in the experiment.
   a. Volume is the dependent variable, and pressure is the independent variable.
   b. Volume is the independent variable, and pressure is the dependent variable.
   c. Both volume and pressure are independent variables.
   d. More information about the experiment must be given to determine the variables.
2. Consider the research question, “Does changing the volume of a gas affect the gas pressure?” Identify the controlled variable(s) that would need to be identified for the experiment.
   a. Volume.
   b. Temperature.
   c. Mass of gas.
   d. Both A and B.
   e. Both B and C.
3. Your class has been directed to investigate factors that affect the rate of reaction when Alka-Seltzer reacts with vinegar. Design an experiment to investigate one variable that might affect the rate of reaction. Write an appropriate research question and identify the independent, dependent, and controlled variables for the experiment.

Student Assessment Questions – Organizing Data

Questions

1. Which of the following states the correct arrangement of data in a scatter plot?
   - *a.* Dependent variable data is plotted as X and independent variable data is plotted as Y.
   - *b.* Independent variable data is plotted as X and dependent variable data is plotted as Y.
   - *c.* Time is always plotted as X.
   - *d.* The variable with the smaller values is plotted as X.
2. Which of these experimental questions would produce data best displayed on a bar graph?
   - *a.* How does the solubility of oxygen gas change as the temperature of the water changes?
   - *b.* What is the effect of increased molecular mass on the boiling point of hydrocarbons?
   - *c.* What is the average height for each of four different varieties of corn plants?
   - *d.* How does a swimmer's body temperature change as he or she completes a swim in cold water?
3. Students in physics class are asked to find the relationship between the length of a pendulum (string with a weight at the bottom) and the time it takes for one pendulum swing. Reorganize the data in a new table to show a possible relationship between the variables, and state the relationship, if any, between the independent and dependent variables.

Group Number	Length of String (m)	Angle of Release (degrees)	Mass at End of String (g)	Time for One Swing (s)
Group 1	0.25	60	500	1.00
Group 2	1.00	60	500	2.01
Group 3	0.50	60	500	1.42
Group 4	1.50	60	500	2.46
Group 5	0.30	60	500	1.10

Student Assessment Questions – Significant Digits and Measurement

Questions

1. Burets are often used to carefully measure the amount of liquid added to a reaction. The long thin buret tube is marked every milliliter and every tenth of a milliliter. Which of the following measurements is correct for a volume of liquid in a buret?
   a. 30 mL
   b. 32 mL
   c. 32.0 mL
   d. 32.01 mL
2. Which of the following measurements was recorded to 3 significant digits?
   a. 30 mL
   b. 32 mL
   c. 32.0 mL
   d. 32.01 mL
3. A student properly records a volume measurement from a graduated cylinder as 30.4 mL. What marks were on the graduated cylinder? (You may draw a picture to answer this question.)

Student Assessment Questions – Significant Zeros

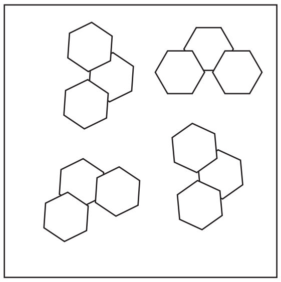
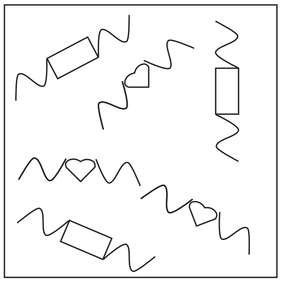
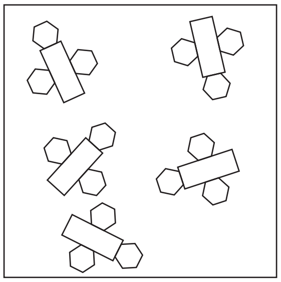
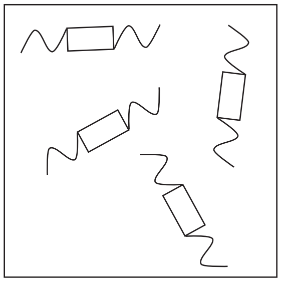
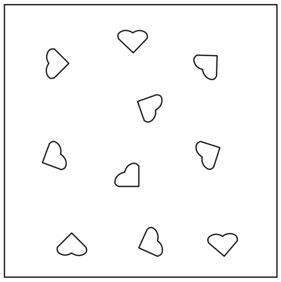
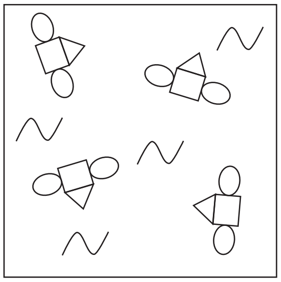
Questions

1. Which of the following measured values has four significant digits?
   - *a.* 4500 m
   - *b.* 0.045 m
   - *c.* 0.0045 m
   - *d.* 45.00 m
   - *e.* 0.450 m
2. Underline the significant digits in the measurement 0.0020750 m?
3. Using complete sentences, explain the difference between the recorded measurements 870 m and 870.0 m.

Student Assessment Questions – Classification of Matter

Questions

1. Identify each of the drawings below as an element, a compound or a mixture.

2. Identify each of the common items below as an element, a compound or a mixture. Their chemical formulas have been given to help you out.

   A. Sugar ($C_6H_{12}O_6$)
   B. Phosphorus (P_4)
   C. Battery Acid (H_2SO_4)
   D. Air (N_2 & O_2 & Ar & CO_2…)
   E. Oxygen (O_2)
   F. Milk ($C_{12}H_{22}O_{11}$ & H_2O & $C_{50}H_{10}2O_3$…)
   G. Gold (Au)
   H. Granite (SiO_2 & $KAlSi_3O_3$ & $K_3Si_3O_{10}$…)
   I. Drain cleaner (Al & NaOH & …)
   J. Sodium (Na)
   K. Water (H_2O)
   L. Salt water (NaCl & H_2O)

3. Which of the following is NOT a true statement?

   a. Two or more atoms held together with bonds make up a molecule.

   b. Pure substances are made of only one type of atom.

   c. At least two types of atoms are required to make a compound.

   d. Mixtures can be made of two elements, two compounds or an element and a compound.

Student Assessment Questions – Isotopes

Questions

1. A neutral atom has 14 protons and 18 neutrons. Choose the correct nuclide symbol for this atom.

   a. ${}^{32}_{18}\mathrm{Ar}$ *b.* ${}^{32}_{14}\mathrm{Si}$ *c.* ${}^{18}_{14}\mathrm{Si}$ *d.* ${}^{14}_{32}\mathrm{Ge}$

2. Which of the following pairs show two atoms with the same number of neutrons?

   a. ${}^{37}_{17}\mathrm{Cl}$ and ${}^{38}_{18}\mathrm{Ar}$ *c.* ${}^{59}_{27}\mathrm{Co}$ and ${}^{61}_{27}\mathrm{Co}$

   b. ${}^{32}_{15}\mathrm{P}$ and ${}^{32}_{16}\mathrm{S}$ *d.* ${}^{65}_{30}\mathrm{Zn}$ and ${}^{67}_{30}\mathrm{Zn}$

3. There are three stable isotopes of Argon: Argon-36, Argon-38, and Argon-40. What would the atoms of these isotopes have in common? What would be different about their atoms?

Student Assessment Questions – Ions

Questions

1. Choose the correct statement.
   a. Metals make positive cations and nonmetals make negative anions.

   b. Metals make negative cations and nonmetals make positive anions.

   c. Metals make positive anions and nonmetals make negative cations.

   d. Metals make negative anions and nonmetals make positive cations.

2. What is the charge on an ion with 21 protons, 25 neutrons, and 18 electrons?
   a. 4+
   b. 3+
   c. 4–
   d. 4+
3. Write the nuclide symbol for an ion with 26 protons, 30 neutrons, and 23 electrons.

Student Assessment Questions – Average Atomic Mass

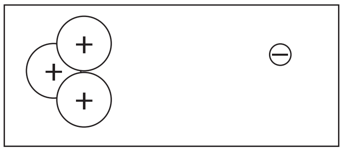
Questions

1. The average atomic mass of nitrogen is 14.0067 amu. Predict which isotope listed below is most abundant in nature?
   - *a.* Nitrogen-13
   - *b.* Nitrogen-14
   - *c.* Nitrogen-15
2. Explain why a weighted average is used to calculate the average atomic mass of an element. Why is it not sufficient to calculate a simple average of the isotope data?
3. A mystery element, called "muriaticum" by its discoverer, exists on Earth as a mixture of two isotopes. The most abundant isotope (75.76%) has a mass of 34.9689 amu; the other isotope (24.24%) has a mass of 36.9659 amu. Calculate the average atomic mass and identify the element by its modern name.

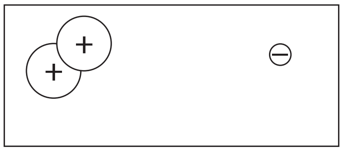
Student Assessment Questions – Coulombic Attraction

Questions

1. Rank the following sets of particles in order of INCREASING force of attraction on the electron.



Set A



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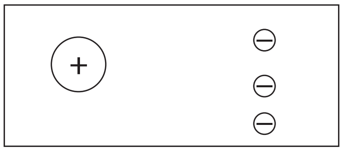
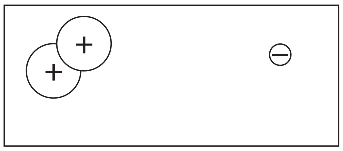
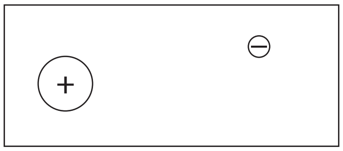


Set C

2. Rank the following sets of particles in order of INCREASING force of attraction on the electron.



Set A



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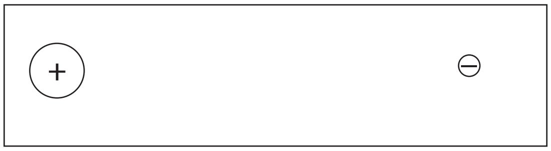


Set C

3. Which of the sets of elements are NOT in order of INCREASING force of attraction on the outermost electron in atoms of that element?

   a. Ba < Sr < Ca

   b. Al < P < Cl

   c. F < Cl < Br

   d. Mo < Pd < Sn

Student Assessment Questions – Electron Energy and Light

Questions

1. Which color of light has the shortest wavelength?

   a. red *b.* yellow *c.* blue *d.* violet

2. Which color of light has the most energy?

   a. red *b.* yellow *c.* blue *d.* violet

3. An electron falls from the 4th energy level down to the 1st. Another electron falls from the 2nd energy level to the 1st.

   a. Which move has a larger change in energy?

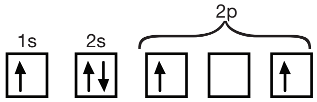
   b. Which move will produce light with the longer wavelength?

Student Assessment Questions – Electron Configurations

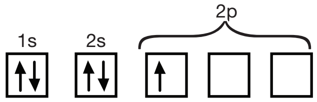
Questions

1. Which orbital diagram represents a boron atom in the ground state?

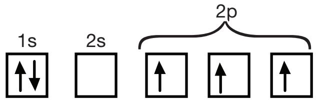
a.



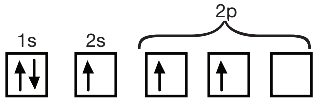
b.



c.



d.



2. Write the ground state electron configuration for chlorine.

3. Match the definition to the correct "rule."

_____ A. Aufbau principle

_____ B. Pauli exclusion principle

_____ C. Hund's rule

I. Electrons in orbitals must have opposite spins.

II. Electrons are placed in individual orbitals of equal energy before they are paired up in a single orbital.

III. Electrons will fill orbitals in order of increasing energy levels—lowest energy first.

Student Assessment Questions – Cracking the Periodic Table Code

Questions

1. Using only a periodic table, identify which set of electron sublevels is NOT organized from lowest energy to highest energy.

   a. 2s, 2p, 3s, 3p, 3d, 4s

   b. 1s, 2s, 2p, 3s, 3p, 4s

   c. 2s, 2p, 3s, 3p, 4s, 3d

   d. 5s, 4d, 5p, 6s, 4f, 5d

2. Which element would have **$4f^4$** as the last entry of its electron configuration?

   a. Cr

   b. Nd

   c. W

   d. Se

3. Write the expected ground state electron configuration for atoms of the element hafnium (Hf).

Student Assessment Questions – Periodic Trends

Questions

1. Which statement of metallic properties is correct?
   - *a.* Small radius, high ionization energy, high electronegativity.
   - *b.* Large radius, high ionization energy, high electronegativity.
   - *c.* Large radius, low ionization energy, high electronegativity.
   - *d.* Large radius, low ionization energy, low electronegativity.
2. Explain why rubidium would have a larger atomic radius than lithium or iodine. Make sure your answer includes comments about both lithium and iodine.
3. Rank nitrogen, calcium, and arsenic from smallest to largest ability to attract electrons from a different atom in a bond. Explain your reasoning.

Student Assessment Questions – Naming Ionic Compounds

Questions

1. Which of the following is the correct name for PbO_2?

   a. lead oxide
   c. lead(II) oxide
   b. lead(I) oxide
   d. lead(IV) oxide

2. Which of the following is the correct chemical formula for iron(III) sulfide ?

   a. Fe_3S
   c. FeS
   b. FeS_3
   d. Fe_2S_3

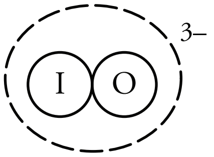
3. In a complete sentence, explain why the name “magnesium chloride” for $MgCl_2$ does not include a Roman numeral.

Student Assessment Questions – Polyatomic Ions

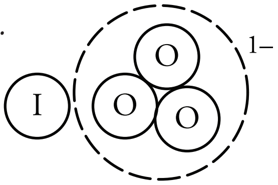
Questions

1. Iodate is a polyatomic ion with the formula IO_3^{1-}. Which of the following drawings best represents this ion's structure?

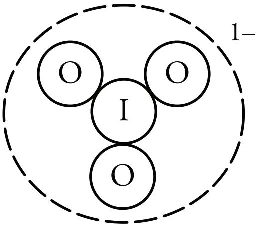
a.



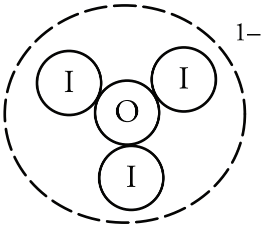
b.



c.



d.



2. Which of the following is the correct chemical formula for zinc nitrate?

a. $ZnNO_3$ *b.* Zn_2NO_3 *c.* $Zn_2(NO_3)$ *d.* $Zn(NO_3)_2$

3. Write the chemical formula for each ionic compound shown below.

Sodium bicarbonate Silver sulfate Aluminum nitrite

Student Assessment Questions – Naming Molecular Compounds

Questions

1. What is the correct name for PCl_3?
   - *a.* Monophosphorus tetrachloride
   - *b.* Phosphorus trichloride
   - *c.* Phosphorus tetrachloride
   - *d.* Monophosphorus trichloride
2. What is the correct formula for tetraphosphorus decoxide?
   - *a.* P_2O_5
   - *b.* P_3O_{10}
   - *c.* P_4O_{10}
   - *d.* P_5O_{10}
3. Why is CO named carbon monoxide rather than monocarbon monoxide?

Student Assessment Questions – Naming Acids

Questions

1. The correct formula for hydroiodic acid is:

   a. HF *b.* HIOS *c.* HI *d.* HIO_4

2. The correct name for H_3PO_3 is:

   a. Hypophosphoric acid *c.* Phosphoric acid

   b. Hydrophosphoric acid *d.* Phosphorous acid

3. When an acid contains a polyatomic ion with an –ate ending, what is the ending in the acid name? Give an example listing a polyatomic ion and its acid.

Student Assessment Questions – Molecular Geometry

Questions

1. What is the shape of AsH_3?

   a. Tetrahedral
   c. Trigonal planar
   b. Bent
   d. Pyramidal

2. Why are Lewis structures important in determining the shape of a molecule?

3. How do lone pairs of electrons affect the bond angle differently than electrons shared in a bond?

Student Assessment Questions – Types of Chemical Reactions

Questions

1. Which of the following reactions is a single replacement?

   a. $NH_3(g) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq)$

   b. $Ca(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow CaSO_4(s) + 2NaNO_3(aq)$

   c. $K_2CO_3(s) \rightarrow K_2O(s) + CO_2(g)$

   d. $MgI_2(aq) + Br_2(l) \rightarrow MgBr_2(aq) + I_2(s)$

2. Identify the type of reaction below and predict the products that would be observed.

   $Fe(NO_3)_3(aq) + CaSO_4(aq) \rightarrow$

3. Identify the type of reaction below and predict the product(s) that would be observed.

   $Cu(s) + O_2(g) \rightarrow$

Student Assessment Questions – Relative Mass and the Mole

Questions

1. What is the mass of one mole of copper(II) sulfate ($CuSO_4$)?

   a. 159.61 amu　*b.* 159.61 g　*c.* 9.61×10^{25} g　*d.* None of the above.

2. How many molecules are in a 44.0 g sample of carbon dioxide (CO_2)?

   a. one　*b.* 44　*c.* 6.022×10^{23}　*d.* 2.65×10^{25}

3. A scientist is working with two compounds. Compound A has a mass of 20.00 amu. Compound B has a mass of 60.00 amu. How will the number of molecules in 5.00 g of Compound A compare to number of molecules in 15.00 g of Compound B?

Student Assessment Questions – Mole Ratios

Questions

1. How many moles of oxygen (O_2) are needed to make 14.0 moles of lead(II) oxide (PbO)?

   $2Pb(s) + O_2(g) \rightarrow 2PbO(s)$

   a. 14.0 moles

   b. 28.0 moles

   c. 7.00 moles

   d. 3.50 moles

2. What mass of boron trifluoride (BF_3) can be made from 30.0 g of fluorine (F_2)?

   $2B(s) + 3F_2(g) \rightarrow 2BF_3(g)$

   a. 20.0 g

   b. 15.7 g

   c. 35.3 g

   d. 31.5 g

3. Iron turns to rust by the reaction $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

   Calculate the mass of iron needed to fully react with 18.0 moles of oxygen gas.

Student Assessment Questions – Limiting and Excess Reactants

Questions

1. Consider the following chemical reaction: $3H_2 + N_2 \rightarrow 2NH_3$. If you are given 6 molecules of H_2 and 4 molecules of N_2, what is the limiting reactant?

   a. H_2

   b. N_2

   c. NH_3

   d. None of the above.

2. Consider the following chemical reaction: $2KCl + 3O_2 \rightarrow 2KClO_3$. If you are given 100.0 moles of KCl and 100.0 moles of O_2, what is the limiting reactant?

   a. $KClO_3$

   b. KCl

   c. O_2

   d. None of the above.

3. Explain what a limiting reactant is to a student who has been absent from this class for a few days.

Student Assessment Questions – Gas Variables

Questions

1. Select the equation below that gives the correct relationship between the internal pressure of a gas and the volume of a flexible container.

   a. $P = k/v$

   b. $P = kV$

   c. $V = kP$

   d. $k = p/V$

2. Explain, on the molecular level, the change in internal pressure of a gas sample in a nonflexible container when the temperature is raised.

3. Explain, on the molecular level, the change in volume in a flexible container when more gas is added.

Student Assessment Questions – Saturated and Unsaturated Solutions

Questions

1. You are given a small beaker of solution at room temperature. You add a bit of solute to the solution and it dissolves. The solution was:

   a. saturated

   b. unsaturated

   c. concentrated

   d. warm

2. Crystals of alum, sugar, or copper(II) sulfate are made by hanging a string in a solution of the substance. Is this solution saturated or unsaturated? Explain.

3. Sketch a beaker with a volume of solvent.

   a. Draw ten total solute particles in the beaker to represent a saturated solution.

   b. If five additional solute particles are stirred in, and the temperature is kept constant, sketch the appearance of the resulting mixture in the beaker.

Student Assessment Questions – Solubility

Questions

1. Which ratio below correctly describes the solubility of solute X.

   a. $\frac{54.0\text{ g X}}{100\text{ mL }H_2O}$ *c.* $\frac{100\text{ g }H_2O}{54.0\text{ g X}}$

   b. $\frac{54.0\text{ g X}}{1.0\text{ L }H_2O}$ *d.* $\frac{54.0\text{ g X}}{100.0\text{ g }H_2O}$

2. A saturated solution of copper(II) nitrate is allowed to sit on a countertop for several days. The volume of the solution decreases as water evaporates from the beaker. Describe the changes (if any) that would be observed in the beaker, and the changes (if any) to the solubility of copper(II) nitrate in the beaker.

3. Substance Y has a reported solubility of 52 g/100 g H_2O. What mass of water would be needed to dissolve 130 g of Substance Y? Show your calculation.

Student Assessment Questions – Molarity

Questions

1. A solution that is more concentrated

    a. is always darker than a dilute solution.

    b. has a lower molarity.

    c. contains more dissolved particles.

    d. has a greater volume.

2. Two solutions of NaCl both contain 0.2 moles of NaCl, but they have different molarities. Explain how this is possible.

3. Calculate the molarity of a KCl solution containing 0.75 moles of KCl in 250 mL of solution. Show all work, including units.

Student Assessment Questions – Calorimetry

Questions

1. Calculate how much heat energy is absorbed by 125 g of water if the water temperature increases by 7.5 °C.

   a. 3.9 J

   b. 69.7 J

   c. 224 J

   d. 3,900 J

2. Calculate the change in temperature when 10.0 g of water releases 150.0 J of heat energy.

3. How much water can be heated 20.0 °C with 1,000.0 J of heat energy?

Student Assessment Questions – Bond Energy

Questions

1. Which of the following statements is true?

   a. The breaking of bonds is exothermic, and therefore has a negative ΔH value.

   b. The breaking of bonds is exothermic, and therefore has a positive ΔH value.

   c. The breaking of bonds is endothermic, and therefore has a negative ΔH value.

   d. The breaking of bonds is endothermic, and therefore has a positive ΔH value.

2. Explain why it is necessary to draw Lewis dot diagrams for each molecule involved in a reaction in order to estimate the enthalpy change in the reaction using average bond energies.

3. Use the table of average bond energies in Model 2 to estimate the change in enthalpy for the following reaction.

   $CH_4 + 2Cl_2 \rightarrow CH_2Cl_2 + 2HCl$

Student Assessment Questions – Equilibrium

Questions

1. Describe the changes in concentration of reactants and products as a reaction approaches equilibrium.

2. Which of the following correctly describes a reaction system at equilibrium?

   a. All reactions stop at equilibrium.

   b. Reactions continue to occur, but there are no detectable changes in concentration.

   c. Reactions continue to occur and concentrations can increase or decrease.

   d. Reactions continue to occur, decreasing all concentrations.

3. Which of the following is required for a reaction to reach equilibrium?

   a. The reaction must be reversible.

   b. The reaction must have only one reactant.

   c. The products and reactants must be equal in concentration.

   d. The forward reaction.

Student Assessment Questions – Acids and Bases

Questions

1. Which of the following is *not* an acid?

   a. HCl *b.* H_2SO_4 *c.* HCN *d.* $Ca(OH)_2$

2. Identify the conjugate acid–base pairs in the following reaction.

   $H_2SO_4 + HPO_4^{2-} \rightarrow HSO_4^{-} + H_2PO_4^{-}$

3. A student checked household ammonia [$NH_3(aq)$] with litmus paper. The paper turned blue. Describe ammonia in terms of acids and bases.

Student Assessment Questions – Strong versus Weak Acids

Questions

1. Assuming they have the same initial concentration, will a strong or a weak acid produce more H_3O^+ ions? Explain your answer.

2. You use a conductivity tester to test two acid solutions having equal concentrations—H_2SO_4 and CH_3COOH. The H_2SO_4 solution is a strong conductor. The CH_3COOH solution is a weak conductor. This is because:

   a. the H_2SO_4 molecules do not ionize in solution.

   b. the CH_3COOH molecules do not ionize in solution.

   c. a larger percent of H_2SO_4 molecules ionize than CH_3COOH molecules.

   d. a smaller percent of H_2SO_4 molecules ionize than CH_3COOH molecules.

3. Which of the following is the correct ionization reaction for hydrocyanic acid (HCN), a weak acid?

   a. $HCN(g) \rightarrow H^+(aq) + CN^-(aq)$

   b. $HCN(g) \rightleftarrows H^+(aq) + CN^-(aq)$

   c. $HCN(g) + H_2O(l) \rightarrow H_3O^+(aq) + CN^-(aq)$

   d. $HCN(g) + H_2O(l) \rightleftarrows H_3O^+(aq) + CN^-(aq)$

Student Assessment Questions – Calculating pH

Questions

1. Estimate the pH of a solution with a hydronium ion concentration of 3.4×10^{-2} M. Do NOT use a calculator.

   a. 1.5   *b.* 2.0   *c.* 3.4   *d.* 6.8

2. As a solution becomes more basic:

   a. [H_3O^+] increases while [OH^-] decreases.

   b. [H_3O^+] decreases while [OH^-] increases.

   c. Both [H_3O^+] and [OH^-] increase.

   d. Both [H_3O^+] and [OH^-] decrease.

3. What is the pH of a solution with a hydronium ion concentration of 1.0×10^{-1} M? Is this solution acidic or basic?

Student Assessment Questions – Oxidation and Reduction

Questions

1. Which of the following reactions is NOT a redox reaction?

   a. $2Al(s) + 3CuCl_2(aq) \rightarrow 2AlCl_3(aq) + 3Cu(s)$

   b. $2NaCl(s) \rightarrow 2Na(s) + Cl_2(g)$

   c. $H_2O(l) + Cr_2O_7^{2-}(aq) + 2Cu+(aq) \rightarrow 2Cu^{2+}(aq) + 2CrO_4^{2-}(aq) + 2H^+(aq)$

   d. $MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$

2. Identify the element that is oxidized in the following redox reaction.

   $H_2SO_4(aq) + Mg(s) \rightarrow H_2(g) + MgSO_4(aq)$

3. Determine the overall balanced redox reaction that occurs when the following half-reactions are combined.

$$2H^+(aq) + ClO_4^-(aq) + 2e^- \rightarrow ClO_3^-(aq) + H_2O(l)$$

$$Al(s) \rightarrow Al^{3+}(aq) + 3e^-$$

Student Assessment Questions – The Activity Series

Questions

1. Given the following experimental results, which metal is more active?

Experiment 1	**Experiment 2**
Zinc metal with iron ions	**Iron metal with zinc ions**
$Zn(s) + Fe^{2+}(aq) \rightarrow Fe(s) + Zn^{2+}(aq)$	$Fe(s) + Zn^{2+}(aq) \rightarrow Zn(s) + Fe^{2+}(aq)$
Reaction occurs	*No reaction occurs*

a. Fe > Zn

b. Zn > Fe

c. Zn and Fe are equally active.

d. No way to tell from the experimental evidence presented.

2. Write a chemical equation for the spontaneous redox reaction between calcium and iron.

3. Draw a before-and-after diagram for the reaction between aluminum metal and a solution of tin(II) ions.

Student Assessment Questions – Batteries

Questions

1. As the voltaic cell (battery) produces electricity, the anode will:

   a. lose electrons. *b.* gain electrons. *c.* not react.

2. A salt bridge is needed in a battery (voltaic cell) so that:

   a. the salt has somewhere to be.

   b. the circuit is completed and electrons can travel through the aqueous solutions.

   c. salt ions can move into the solutions to balance the overall charge in each solution and keep it neutral.

   d. it has no special function and is not needed.

3. Draw a voltaic cell that includes Al and Cu as the metals. Label the following parts of your drawing: metals, ions, anode, cathode, site of reduction, site of oxidation, salt bridge, wires, bulb, and an arrow to show the direction of electron flow.